The Evolution of the Concept of Sleep and Movement Behaviour to the UK High Performance Sport Industry

By

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Forward

This thesis has been a significant part of my working life for the past five years, but it is much more than that. It is the apotheosis of a career in high performance sport, spanning six Olympic/Paralympic cycles and supporting many athletes to podium success(es). It is to those athletes, past and present, that I partly dedicate this thesis, for without them, my idea for the concept of fatigue management would not have been born, nor would the drive and motivation to pursue it as a valuable tool for practitioners to assist athletes be the best they can be in their chosen sport.

I hope through reading this thesis you are left with a sense of what it is to be part of an evolving industry with the eyes of the world upon you and it. The UK high performance industry has transformed itself over the last 20 years and I have been fortunate enough to be right in the heart of that change, the pinnacle being a home Olympic and Paralympic Games in 2012. Parallel to this has been my work with British Rowing; one of the most successful Olympic and Paralympic sports in the world. This has been a dream come true and I am humbled to have experienced being part of a world class system for the majority of my career to date. It is from these experiences that this thesis was born.

In producing this thesis there are many people to thank, Sport Wales for giving me the chance to grow my career in the first place and to the UK Sport high performance system as a whole for nurturing my career and providing pathways for its development. To Professor Zoe Knowles for her help in my attempts to utilise qualitative methodologies and Professor Louis Passfield for his unending positivity, helpful voice and a valuable co-explorer of London cafes! To my family for always being there, Mum and Dad for their eternal enthusiasm and attempts to understand what it is a Sports Scientist actually does! Without a doubt, the biggest factor in making this thesis a success is my husband, and children, for whom I hope this makes them proud. They are my constant and for whom I strive to be better at what I do. Always.

Sarah Gilchrist, July 2018

Declaration

Note, no part of this thesis has been submitted in support of an application for any degree or other qualification of the University of Kent, or any other University or Institution of learning.

Relevant Accomplishments

During the time frame of this thesis I was awarded British Association of Sport and Exercise Sciences (BASES) practitioner of the year in 2012.

I also presentend a prize winning presentation at the 2016 BASES Conference: ''Sleep and movement behaviour characteristics of an international Olympic rowing squad and the influence of domestic living location''. For this presentation, I was awarded the Routledge Recently Qualified Researcher Free Communication Presentation Award.

Additionally, I have been BASES Accredited since 2000, achieving High Performance Addcreditation and Re-Accreditation in 2012 and 2017.

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Abstract

The UK high performance industry has evolved and expanded over the last 20 years. Parallel to this has been an upsurge in the Sports Science industry with contemporary practitioners providing more support to elite athletes in a much more comprehensive and scientific manner. 'What it Takes to Win' (WITTW) models now form a strategic part of the performance planning process and many factors impact on WITTW variables. Fatigue management, through assessment of sleep and also, associated daytime movement behaviour, is an example of such a factor. I collectively term the assessment of both these variables 'Fatigue Management'. Limited knowledge exists regarding sleep characteristics and movement behaviour of elite athletes. Therefore, I present in this thesis the evolution of the concept of fatigue management practices (through athlete sleep and associated movement behaviour assessment), and show how it has been included in the routine methods of Sports Science and Medicine practitioners. Whilst sleep remains a poorly understood entity there is evidence of a reciprocal relationship between sleep and athletic performance with disturbed sleep having a detrimental effect on psycho-physiological processes. In the absence of an effective fatigue management strategy this can be particularly problematic for elite athletes. A technical description of sleep and associated movement behaviour are presented along with methodologies for fatigue management assessment and details of projects using fatigue management strategies. To add context and insight, subjective findings of the impact of introducing this new concept within UK high performance sports' programmes are presented. I present that physiologists should assess fatigue management in the elite athletes they support and use this assessment for dialogue with coaches and sports science and medicine peers, to ensure provision of optimal fatigue management strategies in the performance programmes with which they work. Finally, success factors, methods of optimal practice and future recommendations for an effective fatigue management strategy are presented.

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Abbreviations

General

BASES	British Association of Sport and Exercise Sciences
BOA	British Olympic Association
BPA	British Paralympic Association
BR	British Rowing
BRT	British Rowing Team
CVESS	Classifying the Validity of Expert Samples in Sport
EIS	English Institute of Sport
HPSI	High Performance Sport Industry
HCSI	Home Country Sports Institute
NGB	National Governing Body
MDT	Multidisciplinary team
Team GB	Team Great Britain
Paralympics GB	Paralympics Great Britain
WITTW	What it Takes to Win

Sleep Variables

AAS	Ascending arousal system
AST	Actual sleep time (hr:mm). The total time spent in sleep according to the epoch-by-epoch wake/sleep categorisation
DBAS	Dysfunctional beliefs about sleep
ECG	Electrocardiogram
EEG	Electroencephalogram
EMG	Electromyogram
EOG	Electroculogram

ESS	Epworth sleepiness scale
FI	Fragmentation Index. The sum of the mobile time (%) and the immobile bouts <=1min (%). This is an indication of the degree of fragmentation of the sleep period, and can be used as an indication of sleep quality (or the lack of it)
FIRST	Ford Insomnia Response to Stress
GUT	Get up time (hr:mm). The time the actiwatch recognises get up time determined by pressing button on watch or watch detects 'light'
IT	Immobile time (%). The immobile time expressed as a percentage of the assumed sleep time
MEQ	Morningness/Eveningness Questionnaire
MT	Mobile time (%). The mobile time expressed as a percentage of the assumed sleep time
NREM	Non-rapid eye movement sleep (NREM)
PSG	Polysomnography
PSQI	Pittsburgh Sleep Quality Index
REM	Rapid eye movement sleep (REM)
SCN	Suprachiasmic Nucleus
SE	Sleep efficiency (%). Actual sleep time expressed as a percentage of time in bed
SL	Sleep latency (min). The time between "Lights Out" and "Fell Asleep"
SWS	Slow wave sleep
TTB	Time to bed (hr:mm). The time the actiwatch recognises time to bed determined by pressing button on watch or watch detects 'lights out'
TIB	Time in bed (hr:mm). The total elapsed time between the "Lights Out" and "Got Up" times
TST	Total sleep time
VLPO	Ventrolateral preoptic nucleus

WASO	Wake after sleep onset (hr:mm). the amount of time individual spends awake, starting from when they first fall asleep to when they become fully awake and do not attempt to go back to sleep

Overview and Aims

This thesis sits in the context of high performance sport where the environment and culture support the primary objective of achieving senior international championship gold medal performances. Success in high performance sport is multifactorial. Consequently, sports scientists work to identify the specific factors that determine a team or an individual athlete's performance. Once these determinants of performance are established, this knowledge can be used to devise broad models of, 'What it Takes to Win' (WITTW). These WITTW models in turn help to identify where there may be potential for small advances in performance or so-called "marginal gains". Throughout my career I have found that there are many factors which contribute to or influence the determinants of performance; as an example, some obvious ones are, psychological, physical and nutritional. This thesis will specifically focus on the less well understood psycho-physical aspect of sleep and movement behaviour. Sleep being a recurring state over several hours per night, during which the body remains unconscious, eyes closed, nervous system relatively inactive and muscles relaxed. Movement behaviour being the movement volume during waking hours, often known as 'athlete downtime'. For ease throughout the thesis, I will use the term 'fatigue management' as a collective term for both sleep and movement behaviour in relation to their effect on sports performance. I will argue that these two variables, can provide useful information for the optimisation of performance. Both variables can be objectively measured and analysed as sleep quantity and quality, and daytime rest and activity profiles, and captured through the use of Actiwatches. The methodology for using this field tool is described in Chapter 5.

Therefore, the primary aim of this thesis is to describe the evolution of the novel concept and process of 'fatigue management' into the UK high performance sport industry. I will aim to describe the progression from inception of my idea, my supervision of a PhD on ‘sleep and athletic performance’ and associated workflows within the high-performance sport industry to current practices and future recommendations and optimal practices for employing measurement and assessment of fatigue management. Supporting this, and to provide context to the work completed on introducing fatigue management to the high-performance sport arena, I will aim to outline my philosophy as a practitioner in the UK high performance sport system and exemplify the work required in providing sports science support on fatigue management to elite athletes and coaches. I will also provide a description of the determinants of performance and how integral they are to practitioners’ working practices. Further, a technical review of sleep (and associated movement behaviour) and athletic performance will be provided followed by a description of how sleep has been investigated in contemporary sports science literature. Following this description, I shall propose that physiologists should ‘own’ sleep and will present my findings from sports’ projects I have conducted involving fatigue management. These examples will principally be in the sport of Rowing because this is the sport I have worked most closely with throughout my professional doctorate programme. Work with other British National Governing Bodies of Sport will be used to exemplify the success of the Rowing projects. I will also document the associated evolution of the fatigue management concept into other areas of the UK high performance industry as this has also been a key part of my work. This has involved establishing normative data on sleep characteristics in an elite athlete population. The thesis will describe how the evolution of the fatigue management concept felt, to me, pioneering work. That is, the concept developed from being a minor part of my practitioner work programme to a significant service provided throughout the UK high performance sport system, involving doctoral research, education platforms, innovation projects, service delivery and multidisciplinary collaborations. The thesis will culminate with guidelines for optimal practice on how sleep and movement behaviour should be captured, analysed and reported in elite sport given the complex environments practitioners find themselves working within. Finally, I will provide future recommendations and conclusions. This will include a summary of how to introduce a new concept to such an industry and, through qualitative methods employed, observe, understand and encapsulate the impact of introducing the concept of fatigue management into the UK high performance sport system. A summary of the thesis objectives is listed below and for guidance, headlines and links for each Chapter are provided in the subsequent Chapter sequence.

Thesis objectives:

1. To ascertain the growth of Sports Science over the last 20 years and how fatigue management has emerged as part of the industry development

2. To assess current literature relating to sleep and movement behaviour and athletic performance

3. To determine why physiologists should take responsibility for sleep and athletic performance measurement and assessment

4. To provide examples of fatigue management projects in high performance sport and methods of optimal practice for assessment of fatigue management

5. To make recommendations for future research and applied practice in relation to fatigue management of elite athletes

6. To assess the impact of evolving the concept of fatigue management to the UK high performance sport industry

Chapter Sequence

Chapter 1. Setting the Scene: UK High Performance Sport, the 'What it Takes to Win' Model, Practitioner Philosophy and the Idea behind the Concept of Fatigue Management.

Rationale: to provide insight and understanding of the applied sports science industry and my positionality and philosophy as a practitioner within it. To highlight how I pioneered the idea to evolve the concept of fatigue management and athletic performance.

Key Findings:
1. Sports science and the UK high performance sport industry has evolved markedly over the last 20 years
2. Science and technology play a larger role in sport performance than ever before and more scientific practitioners now work within more sports
3. Introduction of the 'What it Takes to Win' (WITTW) concept
4. Determinants of performance are crucial to achieving marginal gains and certain factors impact on determinants of performance; fatigue management, through sleep and associated movement behaviour, is one of these factors
5. My positionality within the sports science industry is summarised
6. The idea to evolve fatigue management practices came from experiential learning through working with athletes on the ground and wider discussions within the UK high performance sport industry and academia

LINK: whilst Sports Science has evolved over the last 20 years, fatigue management practices have not been traditionally utilised by physiologists (or other science and medicine practitioners) within high performance sport. There is a need to describe what sleep and associated movement behaviour are and the evolution of their measurement and assessment within the high-performance sport industry. Feedback from those involved in developing the concept will add insight and context to the thesis.

Chapter 2. Qualitative Methodology

Rationale: Using a qualitative methodology to explore the impact of evolving a concept within the high-performance sport industry.

Key Findings:
1. Qualitative research is not traditionally undertaken in the physiology discipline
2. Qualitative analysis can add substance, context, insight and depth to quantitative findings in the physiology discipline

LINK: the thesis describes the evolution of the sports science industry and fatigue management as a product of that process. Whilst practical examples of fatigue management projects and a description of how the concept was introduced to the UK high-performance sport industry are provided later in the thesis, the impact of such work is typically difficult to quantify. Therefore, a qualitative methodology was employed through individual semi-structured interviews with key practitioners and subsequent representation offered via verbatim quotes. This data on fatigue management strategies adds insight, substance, context and depth to the thesis and is set against a comprehensive understanding of what sleep is and current findings in the sport science literature.

Chapter 3. A Technical Description of Sleep and Associated Movement Behaviour

Rationale: To outline the physiological processes of sleep, provide information on the architecture of sleep and why and how it is an important entity to be considered by physiologists working with high performance athletes and coaches. A description of movement behaviour is also provided.

Key Findings:

1. Sleep has been studied since the early 19th century but remains a modern day mystery despite various attempts to fully describe its purpose
2. As part of its mystery, sleep falls into a number of domains e.g. psychology, neuropsychology, cardio-respiratory medicine and chronobiology (biological rhythms), consequently no one domain 'owns' sleep
3. Sleep is fundamental to physiological processes and highly individualised
4. Sleep involves sleep cycles lasting 90-minutes and within each cycle there is a 4-stage architecture
5. Sleep regulation is achieved through a homeostatic process responding to internal cues for sleep need and a circadian process that responds to external cues
6. Sleep deprivation can be a particular problem for elite athletes
7. Daytime activity volume described as 'movement behaviour' is a novel concept and relates to an athlete's 'downtime'
8. Specific analysis of the frequency, intensity and duration of exercise has been reported in paediatric literature, but the quantification of elite athletes' movement behaviour, monitored with Actigraphy, is not widely reported, if at all
9. The aim is not to assess the *intensity* of activity or rest, but to provide an objective assessment of the *balance* between rest and recovery during waking hours.
10. Implications of capturing such data are;
11. to help and inform athletes, coaches and support staff to understand compromised athletic recovery practices
12. educate athletes on the importance of good generic recovery choices
13. provide normative data on a previously unknown characteristic of elite athletes' lives
14. to make recommendations to the high-performance sport system on areas where athletes felt compromised in their 'downtime'

LINK: Sleep and athletic performance are interlinked. There is need to review the sleep and athletic performance literature and demonstrate why, in an industry where marginal gains are paramount, practitioners should conduct assessment of those factors capable of influencing and enhancing athletic performance. Fatigue management is one of these areas and the assessment of sleep and associated movement behaviour is one of few physiological and psychological factors yet to be fully explored in the athletic domain.

Chapter 4. Sleep Literature and Athletic Performance.

Rationale: to outline the contemporary issues relating to sleep, provide a summary of the academic research on sleep and athletic performance and present argument as to who 'owns' sleep. To provide justifications as to why, as physiologists, we have a responsibility and should take ownership of the assessment and subsequent interventions for fatigue management and athletic performance.

Key Findings:

1. The high-performance athlete's ability to manage fatigue (through sleep and associated movement behaviour) has seldom been considered.
2. The importance of assessing sleep in athletic performance has been queried in terms of the fact that 'we all do it so why measure it'?
3. Modern technologies are often not validated against gold standard methods to quantify sleep
4. Sleep and athletic performance have a reciprocal relationship and this has not yet been fully investigated in the high-performance sport arena, with research outputs claiming 'loose' associations between sleep and recovery.
5. Minimal normative data exists for elite athletes' sleep quality and characteristics and individual requirements for sleep display large variations
6. Poor sleep can affect athletes' physiological function and psychological function.
7. Three areas are identified as risk factors for poor sleep in athletic performance; training, travel and competition
8. Athlete chronotype has an influence on athletes' responses to training at varying times of day.
9. Elite athletes could benefit from more effective sleep management strategies
10. No single discipline 'owns' sleep and it is therefore examined within multiple academic fields however; the applied physiologist is the ideal practitioner to profile it in elite athletes.

LINK: Sleep, associated movement behaviour and their assessment have been defined and explained in the sports science literature. What is needed is information on the methodologies employed to comprehensively assess sleep and associated movement behaviour in the applied setting.

Chapter 5. Methodologies to Measure and Assess Sleep and Movement Behaviour

Rationale: to provide a detailed description of the quantitative methods (objective and subjective) employed to gather sleep and movement behaviour data.

Key Findings:

1. *Sleep quantity* (duration), measured through variables such as time to bed (TTB), time in bed (TIB), get up time (GUT) and total time asleep (TTS).
2. sleep *quality* (described, disturbances), measured through sleep latency (SL), number of awakenings greater than 5 minutes, wake after sleep onset (WASO), sleep efficiency (SE) and fragmentation index (FI)

3. Diurnal activity can be assessed by time spent immobile (%) and mobile (%) during waking hours.
4. Polysomnography (PSG) is the gold standard objective measure of sleep
5. PSG is hard to employ in applied sport settings. It can disrupt athletes' sleep due to unfamiliar surroundings and can provide unnecessary interruption to the training programme through access to facilities
6. Actigraphy is a good field measure of sleep and assessing the pattern of such rest-activity profiles (movement behaviour).
7. Five questionnaires can provide a sufficient spectrum of assessment of subjective perceptions of sleep

LINK: We now know how to assess sleep and associated movement behaviour. There is a need to present how an initial idea from a discreet project with one sport, has developed into an impactful part of routine service delivery to high performance athletes, aimed at harnessing expertise and professionalism around fatigue management. This is compounded by a need to exemplify, using executive summaries, projects in athletic populations relating fatigue management and athletic performance. Parallel to this is a need to develop a portfolio of 'optimal practice', for assessment of fatigue management.

Chapter 6. Fatigue Management Projects within the UK High Performance Sport Industry and Methods of Optimal Practice

Rationale: to provide a narrative as to how fatigue management practices have evolved within the UK high performance sport industry. Providing examples of projects within sports, that exemplify fatigue management findings and practices within high performance sport.

Key Findings:
1. Fatigue management evolved from a pilot project preparing athletes for the demands of a home Olympic games
2. Justification for further research came from my own ideas supported by outputs at international conferences, funding availability for a specific PhD on 'sleep and athletic performance' and a need from practitioners on the ground to be educated
3. Dissemination of information to athletes, coaches and practitioners was achieved through various modes of communication such as workshops, conference posters and infographics
4. Normative data capture and knowledge disseminating platforms have helped to pioneer the introduction of fatigue management and identify additional factors that impact on athletic performance (WITTW)
5. Sports benefited from bespoke projects involving sleep and waking movement behaviour assessment and fatigue management strategies (2010-present day)
6. Studies demonstrated the utility of sleep profiling in the management of athlete sleep
7. Methods of optimal practice identified include consideration of whether situations are simple or complex. The former leaning towards best practice, the latter more towards what constitutes good practice under complex circumstances.
8. Better fatigue management strategies are needed in high performance sport alongside production of an established database of athletic sleep

LINK: there is a need to establish the impact of introducing the concept of sleep and movement behaviour to the high-performance sport industry. This can be facilitated by identifying critical factors for success with this pioneering idea and evolving concept. Impact can also be demonstrated through highlighting the challenges faced and making future recommendations.

Chapter 7. Conclusions and Future Directions

Rationale: to highlight where fatigue management practices have had an impact in the UK high-performance sport industry. To summarise the thesis, identify critical success factors, challenges and provide future directions for effective fatigue management practices in the high-performance sport industry.

Key Findings:

1. Evolving the concept of fatigue management has not been a simple process but collectively involved relationship establishment, engagement, collaboration, assessment of current literature and identification of common links between research and applied settings.
2. Sports have engaged with the concept of fatigue management through assessment of sleep and associated movement behaviour
3. Physiologists should measure and analyse sleep and movement behaviour
4. A pathway to learn how to measure and analyse fatigue management is required (from neophyte to established practitioner)
5. Practitioners need to gain athlete and coaches trust as well as display technical knowledge
6. Critical success factors were athlete and coach buy-in and negating the 'problem' element of sleep
7. Challenges faced were athlete resistance to assessment, expectation management, presentation of message, athlete and coach engagement, demographics and the 'so what?' question
8. A process for fatigue management is presented in brief
9. Future directions are to;
    a. develop a more comprehensive strategy for improving fatigue management in the UK high performance sport system
    b. highlight improvements in fatigue management practices in sports e.g. education interventions for better sleep hygiene, competition strategies focused on including fatigue management
10. Elite athletes and their support personnel are now increasingly aware of how poor fatigue management practices can impact on their performance and these should be a key consideration in evaluating what it takes to win in any given sport.

Chapter 1. Setting the Scene: UK High Performance Sport, the 'What it Takes to Win' Model, Practitioner Philosophy and the Idea behind the Concept of Fatigue Management.

1.1 Introduction: why assess sleep and movement behaviour?

In elite athletes, sleep and overall recovery between training bouts are paramount for optimising delivery of performance in training and competition. Nevertheless, whilst research into sleep and elite athletes is starting to emerge through subjective and objective analysis (Savis 1994, Erlacher *et al*., 2001, Reilly & Edwards, 2007, Mah, 2011, Skein *et al.*, 2011, Leeder *et al.*, 2012 and Zhao *et al.*, 2012), there is nothing reported on the rest-activity profiles (or 'movement behaviour'), of such a population, despite technologies (described in Chapter 5) having the ability to provide such data. Whilst high performance practitioners, coaches, athletes and academic research groups recognise sleep as a critical biological function, rarely has there been a focus on capturing data to inform athletes about their overall fatigue management through sleep and associated movement behaviour.

Yet, capturing descriptive data on movement behaviour (through wake time rest and activity profiles), can provide sports science, medicine and coaching staff with quantitative information on the rest and activity profiles (i.e. downtime) of high performance athletes. This process allows data capture in relation to elite athletes' 'perceived recovery' periods between training and before bedtime and could prove useful for establishing normative data and comparisons of different environments, for example on training camps and during competition. This data could then be used to help improve athletes' knowledge of what good 'downtime' is in terms of quantifiable data and enhance their awareness in making decisions relating to their movement behaviour. It also proves useful when, following recovery guidelines set by coaches or practitioners, an athlete's recall of their recovery proves 'unreliable' and they display signs of insufficient recuperation between training sessions.

To date, little emphasis has been placed on the area of overall fatigue management and athletic performance, neither in the Sports Science academic sphere nor in the applied field context. Consequently, the elite athletes' ability to manage fatigue through sleep or associated movement behaviour has seldom been considered. Supposed reasoning for this is that whilst measurement of athletes' physiology, psychology and technical capabilities and metrics predominate training sessions, adding assessment of sleep to an already hectic assessment battery is often considered too invasive. This view is further enhanced when you consider the athletes home environment as the one place they can escape assessment and monitoring. Further, the area of 'sleep' tends not to be 'owned' by a particular discipline, as it spans the psychological, physiological and medical domains (particularly respiratory medicine). Nevertheless, in an industry where marginal gains are critical for success, assessment of anything capable of influencing and enhancing athletic performance is paramount. Therefore, practitioners should recognise the opportunity for a significant gain(s) in performance and be cognisant to conduct assessment of all such determining factors.

Sleep and associated movement behaviour are examples of such factors, yet sleep is one of the few remaining physiological and psychological aspects yet to be fully explored in the athletic domain. Therefore, there is a clear rationale for practitioners to focus on the characteristics of sleep, its quality, quantity and associated movement behaviour in elite athletes and, as a consequence, highlight areas for improvement. Brailsford (2013), the former Performance Director of British Cycling and Head of Team Sky, a British professional cycling team, comments on this in terms of an approach that encapsulates all matters of performance and specifically highlights sleep as an area for consideration in helping to enhance athlete performances;

> ''People often associate marginal gains with pure technology, but it is far more than that, it is about nutrition, ergonomics, psychology. It is about making sure the riders get a good night's sleep by transporting their own bed and pillow to each hotel. Each improvement may seem trivial, but the cumulative effect can be huge'' (Brailsford, 2013).

1.2 High performance sport

In describing fatigue management as a concept within the UK high performance sport industry and presenting a case for it to be a focus area for Sports Science and Medicine practitioners, it is necessary to provide some brief background to the industry within the UK and beyond.

An array of factors are required for sporting success at the elite level. Certainly, in the modern era Olympic Games, countries of relative economic success are the ones who frequently feature highly in the medal table. Aside from financial input, typical factors for a nations' sporting success include dedication from athletes, coaches and support staff to ensure a plethora of science, medical and technical elements peak precisely on the day(s) of performance. Therefore, as Males (2012) reported, technological and scientific advances in sports, in combination with financial input, can lead to a country's overall success rate in international sporting achievements,

> 'the science of sport performance is now well advanced, and sadly there's an increasing correlation between the amount a country spends and its Olympic success. This is most true for technologically-based sports like sailing or cycling, and least true for relatively low technology based sports like middle and long-distance running'. Males (2012)

In Great Britain for the London 2012 Olympics the UK Sport[1] research and innovation (R&I) budget was over £10 million and was in addition to the Sports' central funding which is received directly from UK sport[2]. This R&I budget secured delivery of over 75 bespoke, customised and one-off projects to a broad range of sports involving customised equipment development, training tools and technologies, and innovative insights into enhanced training and recovery methods for performance development. This financial commitment was then increased for subsequent Rio and Tokyo Olympic/Paralympic cycles respectively. This was a far cry from the 2008 Beijing Olympic cycle where UK Sport invested £1.5millon per year in collaborative projects to enhance the performance of British Olympic and Paralympic athletes. Such a financial commitment to research and innovation in the UK alone over the last 20 years demonstrates that science and technology are factors for sporting success (Greenleaf *et al*, 2001, de Bosscher, 2008, National Research Council Canada, 2018). Certainly, benefits to performance from projects funded through such increased investment have been wide spread, for example the technological and engineering projects of bike design and aerodynamics testing for British Cycling.

Parallel to these developments in UK Sport financial investment, has been the upsurge in Sports Science over the previous three decades. This evolution of the Sports Science industry

[1] Established in 1997 UK Sport is a non-departmental public body of the Department for Culture, Media and Sport.

[2] UK sport have 'central funding' for sporting National Governing Bodies (NGBs), enabling them to operate a World Class Programme (WCP) and ensuring athletes have access to outstanding support personnel and training environments to ensure they are among the best prepared in the world. They also have 'direct to athlete' funding in the shape of an Athlete Performance Award (APA). This award, which is solely funded by National Lottery income, is paid directly to the athletes and contributes to their living and sporting costs.

has seen a significant growth in the role of Sports Science in assisting, improving, and monitoring athlete preparation for major championships, the amount of direct practitioner delivery time to athletes and coaches (Davison & Williams, 2009) and a greater use indirectly, of sports science research influencing practice (Bishop *et al.*, 2006).

Indeed, de Bosscher (2008) reported 'scientific research' as one of the principle drivers of international sporting success and where single investment in this area can provide a competitive advantage. Although Clark & Skiba, (2013) note this research should be based on available evidence through peer reviewed journals and sound reasoning. Whilst this is a scientifically robust approach, unequivocal evidence to answer sports' performance questions is not always present, or possible, in the available literature. Whilst science progresses understanding by publication of evidence following peer-review, elite performance doesn't wait for this. Having a competitive advantage over other nations means that you may employ practices that everybody already knows about and are well-established, but these are in addition to confidentially tracking and acting on more intelligence that other nations do not have access to. Therefore, whilst effective support work necessitates innovative practices, and evidence based practice should be at the forfront of a practioners mind when supporting athletes and coaches, practitioners often find themselves working at the 'cutting edge' of performance gains, where they are the first to trial new methods without any available evidence of performance improvement. Undoubtedly, where practitioners have experienced using innovation in the absence of any available scientific verification, when appropriate, their findings should be disseminated to the wider scientific population for discussion and continuation of cutting edge scientific support (Bishop *et al.* 2006). For example, at the end of an Olympic cycle where competititve advantage is negated post competition.

The worldwide increase in science practitioners working directly with sports, enhances in Coaching and Sports Science research, and in laboratory and field technological developments, has led to a collective uplift in the quality of sports specific physiological monitoring and testing protocols available to elite athletes, and correspondingly, their performances (Hahn, 2013). Therefore, the science of sport and performance has become a more integral component of the high-performance sport industry and, specifically in the UK in answer to such worldwide industry change, we have observed our national sport system undergo a monumental change and emerge to be the envy of the world (Hoy, cited in Kelso, 2012).

A catalyst to this change was the 1995 British Government policy statement 'Raising the Game', which announced the advent of the National Lottery and its investment of £300 million a year in sport which would allow the establishment of a 'British Academy of Sport'. In this statement the Government challenged British sport to establish a regional network of specialist institutes who would provide everything necessary for elite sporting success, from talent identification to scientific and medical resources and training facilities. The institutes' remit would be to develop 'specialist centres in Sports Science and Sports Medicine and also a centre of excellence in research and development' with the focus being to benefit from the worldwide increase in sports scientific literature and applied knowledge and practice.

A further incentive to the cultural shift in the UK sport system was the poor performances of Team GB athletes at the 1996 Atlanta Olympic Games. Simon Clegg the former Chief Executive of the British Olympic Association and who was Deputy Chef de Mission in Atlanta, summarises the gravity of Great Britain's poor performance at this time:

> ''Atlanta was a massive low point. One gold medal, the lowest place in the medal table since the early 1900's, it was a really significant underperformance by the British team, sometimes you get into a downward spiral and it is very hard to get yourself out of it''. (Clegg, cited in Kelso 2012).

Over twenty years have passed since the dismal British performances in the 1996 Atlanta Olympic Games, the government's historic policy statement and the advent of the national lottery. During this time British high performance sport has undergone a transformation unlike anything experienced before in the UK. This is exemplified in the UK sport system where its increases in sports' funding through National Lottery and exchequer pathways have paved the way for sports to employ performance directors, coaches and Sports Science and Medicine practitioners in a much more rigorous and strategic manner. In short, the traditional well-meaning and amateur application has long since been replaced by scientific rigour (Gibson, 2016). As an example, since UK Sport's World Class Performance Programme (WCPP) funding began in 1997, British Rowing's WCPP funding has increased from just under £10 million for the 2000 Sydney Olympic Games to over £32 million for the 2016 Rio Olympic Games.

Certainly, this cultural shift in professionalism and modernisation of British high performance sport has helped attain Team GB's most successful era in Olympic and Paralympic sport where we have improved our medal total performance for five successive games and become the first nation to improve their medal total at the Olympic Games immediately after hosting one.

It is no surprise that this has come about since the advent of support from National Lottery funds (Prenderville, 2016). Figure 1.1 displays Team GB's Olympic success since the aforementioned poor performance at the Atlanta 1996 Olympic Games. Without doubt, the establishment of UK Sport in the late nineteen nineties as the funding body of National Governing Bodies of sport and the creation of the English Institute of Sport[3] five years later, have been fundamental to the changes observed in the success of the UK high performance sport industry. Both these organisations have brought a level of strategic intelligence to the UK high performance sport industry which did not exist prior to the 1996 Atlanta Olympic Games. Thus, the *how* and *when* Sports' finances are spent are considered more than ever before.

Yet increases in the Sports' funding alone have not achieved the podium successes we have witnessed over the last 20 years. Moreover, it is a collective impact from improved governance, culture and people who operate within the UK high performance sport industry. Note the success of the Paralympic GB has paralleled Team GB's success but for brevity I shall refer to Team GB as a global term for the remainder of the thesis.

[3] The EIS is the UK's largest provider of sport science, medicine and technology. The EIS also provides a range of added-value benefits to the sports they work with including world-class performance environments and access to cutting edge innovation and research.

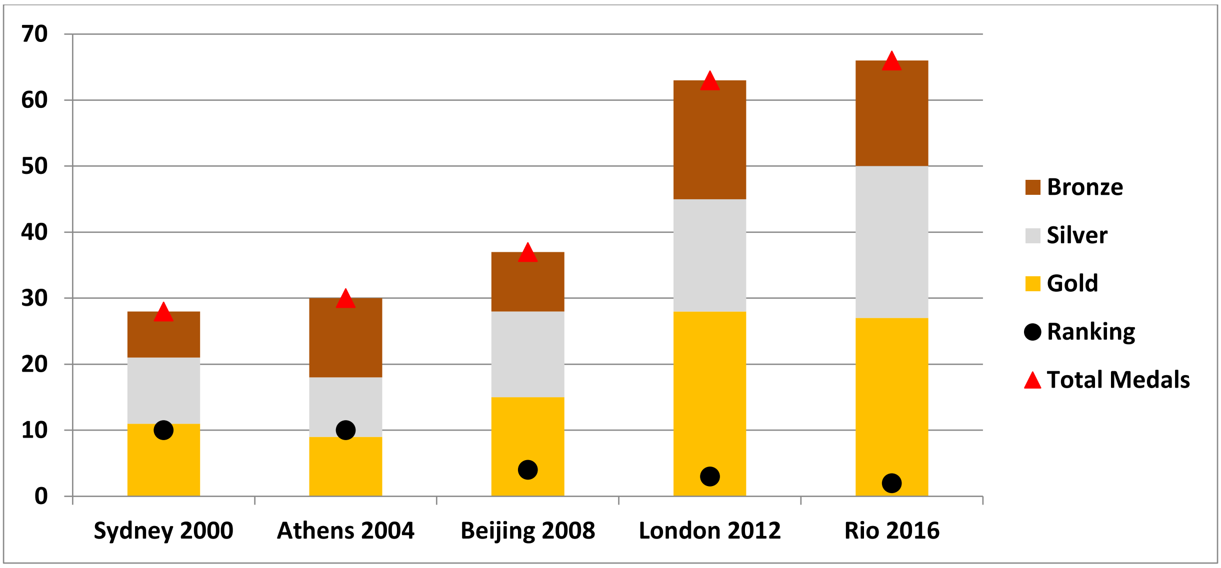

Figure 1.1 Teams GB's success in the last five Olympic Games, including a breakdown of Gold, Silver and Bronze medals, total medals won and overall position (ranking)

1.3 What it Takes to Win (WITTW)

With the evolution of the sports science industry came a concomitant terminology shift associated with winning international medals. Whilst 'marginal gains' were the axiom of the 2008 Olympiad this has evolved into a much more strategic and sport aligned process focusing on determinants of performance or, more commonly termed within British high performance sport, a 'What it Takes to Win' model (WITTW).

The concept of a 'What it Takes to Win' model stems from sports' necessity to aggregate any marginal gains for performance benefit. This referring to the fact that practitioners, like myself, coaches and performance directors should ensure they examine every aspect that might have an effect on an athletes' performance and try to discover ways to improve it. This philosophy applies to any sport and as part of a detailed plan to produce a medal winning performance, the determinants of performance must firstly be identified to increase the chances of medal success. Smith (2003) reported how 'world best sport performances appear to plateau for only a short period before being taken to new levels' so aggregating any gains made becomes part of a larger impact on an athlete's performance. It is the alignment of practitioner's work programme to a sports WITTW model that is the essence of contemporary world class Sports Science and Medicine support programmes.

Because the ability to identify, scrutinise, and improve determinants of performance can lead to the difference between success and failure, WITTW models are significant to a sport's ability to deliver its predicted medal target at Olympic and Paralympic games. For example, at the London 2012 Olympic Games, the time between gold and bronze for track and field's 100 metre men's final and swimming's 50 metre freestyle men's final was only 0.16 and 0.25 seconds respectively. Perhaps more crushing, is for those athletes who finish outside of the medals, but where the performance margins remain tight. For example, if the athlete who achieved 4th place at the London 2012 100 metre men's final had run one percent faster, with the existing field of performances remaining the same, then they would have won a silver medal. Both examples represent small margins in time, but huge voids in terms of performance outcomes for the athletes, coaches and support staff involved, both in terms of performance, funding and, ultimately, sporting history. Similarly, Table 1.1 displays data from the Beijing 2008 Olympics for an array of sports ranging from sprint to endurance, and the difference in medal attainment that a one percent improvement in performance would have made. It presents how, even with a relatively small improvement in performance, 1% would potentially be the difference between finishing in or out of the medals.

Table 1.1 Results from 2008 Beijing Olympics display the difference 1% makes across a range of sports (adapted from Males, 2012)

Event	4th place	1% improvement	Proposed Result
Athletics Men's 100 m (s:ms)	9:93	9:83	Silver
Athletics Women's 400 m (s:ms)	50:01	49:51	Gold
Kayak Men's K1 1000 m (mm:ss.0)	3:29.19	3:27.10	Silver
Swimming Women's 400 m (mm:ss.0)	4:03.60	4:02.61	Gold
Athletics Men's Marathon (h:mm:s)	2:10:21	2:08:7	Silver
Cycling Women's road race (h:mm:s)	3:32:28	3:30:52	Gold

Therefore, in an industry governed by such marginal differences in performances, there is a requirement to identify and scrutinise a sport's performance landscape for 'what it takes to win' and the associated critical determinants leading to such winning performances. Additional to determinants of performance are certain 'impact factors' which interact and influence determinants of performance. Figure 1.2 is an illustration of a how a successful performance model may look with its principle component parts; the winning performance, the determinants of performance and impact factors on those determinants. Fundamentally, the model demonstrates how impact factors exist outside a 'What it Takes to Win' model but, are crucial in their interaction with the critical determinants of performance.

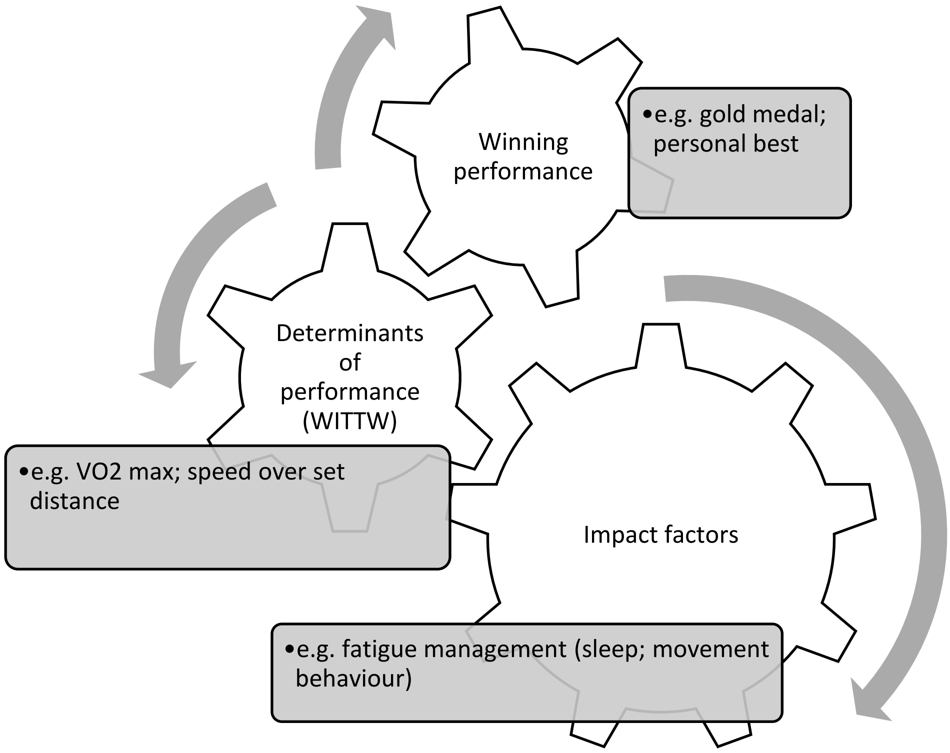

Figure 1.2. Illustration of how fatigue management through sleep and associated movement behaviour can potentially impact on determinants of performance in a 'What it Takes to Win' model

It important to recognise here that there are many determinants that can contribute or impact on an elite athletes' ability to win, for example, psychological, physical and technical. Consequently, there are a myriad of impact factors on such determinants. I present throughout this thesis that fatigue management is one of these potential impact factors on determinants of performance in a 'What it Takes to Win' model.

It is important to note that I am not presenting an argument that fatigue management, through sleep and associated movement behaviour, are isolated variables that will lead to a winning performance. As Davison *et al.* (2009) report, changes in a single variable are unlikely to make a substantial contribution and it is often the accumulation of many changes across all Sports Science (and medicine) disciplines that leads to successful performance. Nevertheless, all factors in a 'What it Takes to Win' model should be considered in preparing for international competition and I therefore argue that sleep and movement behaviour are two factors impacting on such a model. The thesis will therefore specifically focus on the concept of fatigue management, to highlight how sleep and movement behaviour serve as useful 'impact factors' on the optimisation of performance determinants (WITTW models). Figure 1.3 simply demonstrates the interaction between fatigue management and various performance variables, although it must be noted this is not an exhaustive illustration.

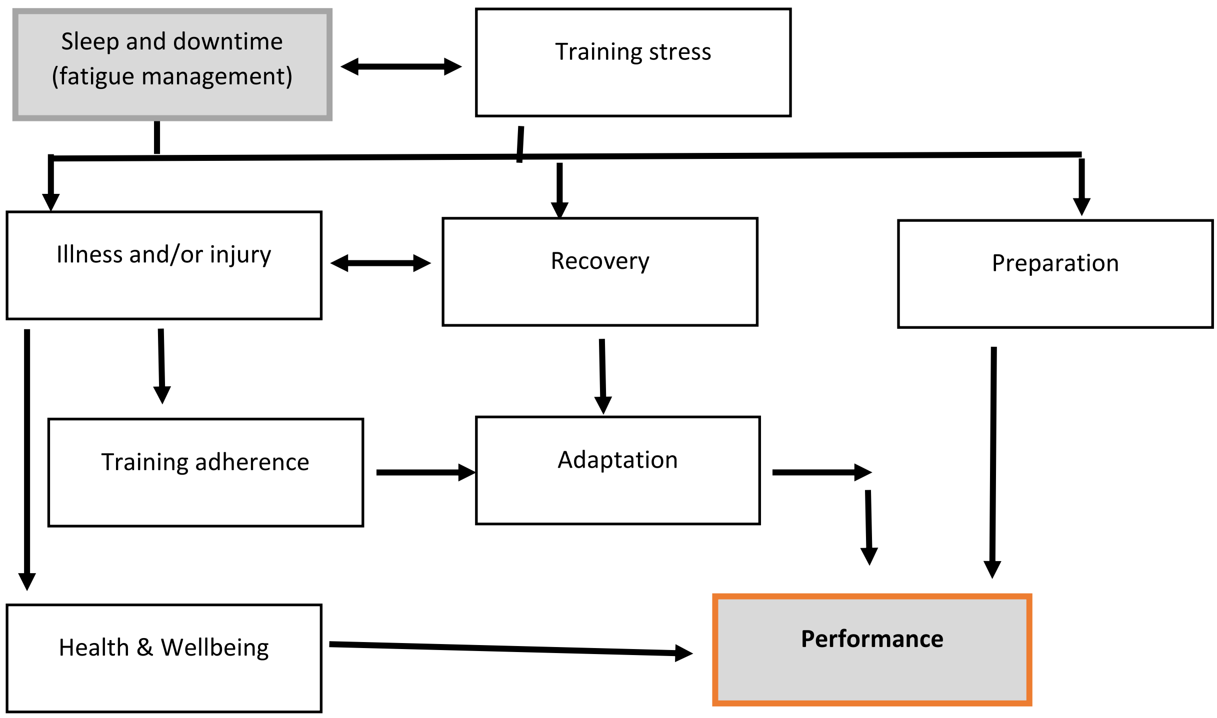

Figure 1.3. The interaction of fatigue management on athletic performance variables (adapted from Gupta 2013)

This thesis will therefore describe how assessment of such impact factors on critical determinants of performance have evolved from being a minor part of my work programme in one Sport, to a significant service provided throughout the UK high performance sport system; involving post-doctoral research, education platforms, service delivery and multidisciplinary team involvement.

The focus will principally be in the sport of Rowing because to date, British Rowing, who are regarded as one of the best rowing nations in the world, have benefitted from projects involving the objective analysis of sleep and daytime rest and activity profiles in elite rowers. They are also the sport with whom I have had the most direct contact over the past 10 years. Squads from 2007 to 2014 will be used as the principle sample population for this thesis. Other Sports will also be used for examples of established normative objective data collected and such project descriptions are pivotal to providing an indication of impact to the UK high performance industry in evolving the concept of fatigue management.

1.4 Practitioner background

I feel it is helpful and important in the first instance to describe my philosophy as a practitioner within the high-performance sport industry ahead of outlining the inception of the idea to evolve the concept of fatigue management within this industry. This section will provide context to my role within the UK high performance sport system and how I came to be in a position to introduce such a novel concept to the industry.

1.4.1 Positionality

During my career to date, I have been fortunate to have been a part of the aforementioned transformation in the UK high performance sport system. My positionality within the Sports Science industry has developed over the last 20 years from a young, neophyte post graduate practitioner embarking on a Sports Science career, to an experienced discipline lead working for a renowned institute of sport, supporting podium athletes in Olympic and Paralympic domains through six Olympic cycles. Most recently, my role has evolved to become more of a performance consultant, specifically focusing on practitioner development, expertise in the UK high performance sport system and a technical specialism in optimal performance and fatigue management (sleep and movement behaviour). This has allowed me to diversify away from the high performance sport industry, yet, maintain a focus on supporting people to achieve optimal performance in a variety of spheres. In all the positions I have held, I feel it has been a privilege and unrivalled experience to be part of a globally evolving industry and to work in a country where high performance sport is high on the political, social and cultural agenda.

With this in mind, writing an autoethnographical and more interpretivist account has been a particular challenge as I am traditionally more familiar with following a positivist form of research i.e. obtaining quantifiable data to interpret and report. However, I have discovered through adopting a more interpretivist approach, that this has allowed me to consider and present a more personal perspective of my background, positionality and philosophy towards being a practitioner in the UK high performance sport system. This is akin to Morton's reflective account where he reported benefits to his professional development through reflecting and reporting in the self-narrative (Morton, 2009). This was a paper the now, Professor James Morton, wrote as a neophyte lecturer, spanning the course of his first year in a full time lecturing position, having recently competed his PhD. In the paper, he writes honestly about his misgivings for writing in a qualitative format and commented on how, as physiologists, reflective practice is quite different to our usual scientific writing style and reporting of quantitative data. This was as seminal paper for me, and the wider Sports Science industry, as at the time, limited reflective practices existed in the exercise physiology field; neither reported in academic literature, nor actively encouraged or coached as part of one's development. For me, Morton's (2009) paper perfectly described the anxieties and triumphs of a neophyte practitioner, albeit working in a quantitative field, yet able to articulate their reflections in such an autoethnographical and academic manner. Reading Morton's (2009) paper, Knowles *et al.'s* book (2014), and writing this thesis in a more interpretivist manner, has enabled me to explore meaning to my personal background and positionality within the high-performance sport industry and to uncover some of my own beliefs of the importance of my work and express its impact. The process has certainly helped me to 'get' reflective practice and become a better practitioner for it (Knowles *et al.,* 2014). Notably, this thesis has made me realise how much of a humanist approach I take when supporting elite athletes. By this I mean that whilst I am their physiologist first and foremost, I like to take into account the athletes 'whole self' in determining their responses to training. This is similar to Morton's (2009) reporting of a humanist approach where he describes, before any intervention, a need to build empathy and a personal relationship with the client, and the need to understand them as a person (Morton, 2009). This is something I can profoundly relate to, as by being more humanistic, and therefore not limiting myself to what the physiological data is telling me, I believe I can be more impactful in my support to the elite athlete(s) I am responsible for. Where I have observed 'data driven only' practices during my experiences in the UK high performance sport system, I have been frustrated in what can be 'missed' by not observing the athlete as a whole and exclusively tracking objective markers. For example, when I first started in the British Rowing programme, we had a case where an athlete unfortunately suffered from unexplained underperformance syndrome (UPS). As a coaching and support team, had we spent a little more time listening to them rather than simply observing data on the water and in the gym e.g. split times and weights lifted, we could have provided interventions earlier in their training to potentially negate the illness occurring. Therefore, by reflecting in such a personal manner whilst writing this thesis, I remain confident the reader has the opportunity to obtain a clear impression of the 'person' behind the scientist and understand the personal reflections of my ontology (existence) and epistemology (knowledge) within my profession.

Since I began my career in the late 1990's, Sports Science has become a more integral component of high performance sport. As described previously, coupled with the increase in the amount of direct practitioner delivery time to athletes and coaches, there is a greater use indirectly of Sports Science research influencing practice (Bishop *et al.*, 2006). These factors of increased knowledge and practitioner delivery and recognition of the impact of Sports Science on athletic performance have not only been pivotal to the development of my profession as a whole but also for my own philosophy towards scientific support in a high-performance sport environment.

1.4.2 Professional practice

Traditionally there has been little emphasis placed on the enquiry into *professional practice* in the majority of sports science disciplines. Specific disciplines tend to vary in their ability to measure the effectiveness of practitioners either qualitatively or quantitatively, although sport psychology is the exception, where, for example, a multitude of literature exists referring to reflective practice and athlete support (Partington and Orlick, 1987, Anderson *et al.*, 2002, Anderson *et al.*, 2004, Cropley *et al.* 2007, Cropley *et al.*, 2010 and Cropley & Hanton, 2011).

In the discipline of physiology (my technical area) there has been little focus on the ability of practitioners to define a philosophy, evaluate and reflect on their practices and consider their own positionality in relation to their profession. Peer reviewed reflective accounts from physiologists are certainly rare in the literature (Morton, 2014). Traditionally physiologists have placed less emphasis on cognitive evaluation and its importance and instead have focused on the individual athlete's physiological outcomes from scientific interventions. The argument appears to be, therefore, that the quality of physiology support work is difficult to quantify in a meaningful way and whilst physiological assessment and sports performance itself can aid athletes and coaches assessment of the impact of physiological support, measuring the impact of physiology on performance in relation to the practitioner involved can be abigiuous. This is frustrating when you consider reflective practices are paramount to achieve high performance both as an athlete and as the practitioner supporting the athlete. As Knowles *et al.* (2007) describes, developing into a practitioner with 'specialist' knowledge in any domain requires a combination of professional knowledge (experience and technical) and tactic knowledge (knowledge that cannot be verbalised), i.e. your values, prejudices and social norms. It is here in the exploration of tacit knowledge where enquiry into professional practice and reflection can be most effective. Further, if you understand the extent of both your *professional* and *tacit* knowledge then your skills as a competent practitioner are enhanced and can impact upon your service delivery (Knowles *et al.*, 2001). Reflection through creative writing (self narrative) plays a key part here as it can help to unleash hidden 'tacit' knowledge through raising conscious awareness, which in turn can drive active reflections (Saylor, 2009, Morton, in Knowles *et al.*, 2014).

In the case of evolving a new concept to the UK high-performance sport industry, the relevance of reflective practice to one's development is an important point. In the process of evolving fatigue management, through sleep and associated movement behaviour, as an area worthy of measurement and analysis, I have strived to develop my awareness and ability to effectively reflect in the knowledge that the ability to enquire into ones' professional practice provides an effective addition to an existing technical and non-technical skill set. This is in essence what this thesis embodies; a reflection on the impact of evolving a new concept (fatigue management) to the high-performance sport industry which allows me to encapsulate how my skills and abilities in problem solving including, innovation, creativity and overall capacity and ability to reflect, have developed.

1.4.3 Philosophy

Fundamentally, my philosophy towards sports science support to high performance athletes and coaches is that it should be performance focused and follow a coach and athlete centered approach. I combine this with the knowledge and dedication that sports science is about making marginal gains in an athlete's performance and establishing 'what it takes to win' from a discipline specific and holistic standpoint. Parallell to this process is a strong adherance to the theoretical principles of athletic training which underpin any scientific input into an athlete's training and performance. As a practitioner, I feel that having the daily technical and non-technical interaction with athletes operating on a world class level enhances one's technical knowledge and skills and also self-awareness in striving to provide a 'world class' support service. For example, monitoring athletes' responses to a training session(s) and also having a global awareness of their recovery on a day to day basis, i.e. what 'load' do they place on themselves other than training? Are they having to work in addition to train? etc. As Thompson (2010) reported, practitioner's often work in difficult and uncertain environments where being 'visible' plays a large part in the success of an intervention being employed, delivered and assessed. Consequently, practitioners often have to balance 'face time' with other elements of their role e.g. project development, audits, data management, in addition to their own development interests in training, research and innovation (Thompson, 2010). This is certainly a concept I have experienced throughout my career, however, throughout this I have maintained that an evaluation of work quality and its influence on high performance athletes and coaches is crucial to effective support work. How my work supporting athletes and coaches is measured and evaluated is, to me, the difference between quality assessment and good professional development, and poor athlete progression and sustained future service provision. The process of providing world class innovative support to athletes and coaches is exemplified through the successful introduction and development of the novel concept of fatigue management and athletic performance and shall be highlighted throughout the thesis.

1.4.4 Accountability

In establishing new concepts to athletes, coaches and support staff, I believe that I need to be accountable for the interventions I am advising athletes and coaches to employ in their performance programmes. Hawkes and Miles (2001) commented that with such an emphasis on the growth of professionalism of the applied sports science industry, there is more of a need for accountability and, in order to be accountable, skills in evaluation need to be developed to allow for assessment of intervention effectiveness and feedback to athletes and coaches. To add, Thompson (pp. 1, 2010) noted how elite sport is judged on results, therefore 'sports scientists operate in a dynamic and volatile environment of accountability where it is difficult to provide effective measures of success of a practitioner quickly'. This concept of accountability coincides with my personal objectives of providing a high standard of physiological support specific to the requirements of the athlete or sport/discipline and ensuring consistency in my working practices through purposely and regularly reflecting on my performances. In initiating a new concept to the UK high performance industry, the issue of accountability was critical. Here, the technical knowledge I gained around fatigue management (sleep and movement behaviour), highlighted in Chapters 3, 4, 5 and 6, became fundamental to the process. In conjunction with my developing technical knowledge, was my ability to influence coaches, athletes and peers as to how the concept aligned into what it takes to win models. In considering accountability, Hawkes and Miles (2001) identified themes for effective practitioners, two of which resonate with the pathway I have taken in establishing a novel concept to the UK high performance sport industry.

1. Knowledge and experience are fundamental to the fact that particular attention should be paid to a solid technical knowledge and understanding of the determinants of performance and the associated physiological requirements for a given sport. In this instance and parallell to this knowledge, was having a good technical understanding of the physiology of sleep (oultined in Chapter 3) and the indivisualised nature of it.

2. A professional practical service is necessary to providing any support to elite athletes and principally when producing new innovative solutions and ideas to sports programmes. Having a proactive innovative approach is important as often research is not available to answer the performance questions in a WITTW model, so using innovative techniques with theoretical underpinnings are crucial. In this instance, understanding the theoretical underpinnings of sleep from a physiological standpoint was cruciual to identifying sleep as an area deserving further research in Sports Science . It also exemplifies how innovative techniques can be transformed into sport programmes by practitoners with an acute

awareness of accountability, the significance of techncial knowledge and the impact on 'What it Takes to Win' models of a given sport.

However, whilst such scientific underpinnings may provide a sound basis for an idea, the practicality of experimentation is limited to 'real world' scenarios and this is where I find reflective practice can be an effective tool for assessing the impact of a particular intervention and my role within that is exemplified throughout this thesis.

1.5 How did the novel concept of fatigue management begin?

The motivation for encouraging the UK high performance sport industry to have a strategy for fatigue management through robust assessment of sleep and movement behaviour, stem from both my experience in the industry (working with elite athletes for over 20 years) and personal intuition (no one was measuring sleep or athlete downtime and I felt the variables needed to be captured). Historically, sleep and athlete performance had been addressed, but only from a travel fatigue standpoint. Downtime hadn't been quantified formerly at all in elite athletes on the basis that practitioners didn't routinely use actigraphy as part of their assessment battery of elite athletes. Additionally, few practitioners had employed this particular function of the actiwatches. Nevertheless, I believe both sleep and movement behaviour are valid objective and subjective monitoring markers of an elite athlete's ability to tolerate training load and the effects of such a training load. This is of course in collaboration with other defined performance markers relevant to a Sport e.g. 2000 metre rowing ergometer time (mm:ss.0).

Standard justifications for analysing and characterising an athlete's sleep and movement behaviour profiles are typically, but not exclusively, related to fatigue management issues within a sport. These can manifest as a medical referral from a sports' Chief Medical Officer to assess either training load management (indications for under-recovery, underperforming, training adherence) (Wall *et al*, 2003, Smith *et al*, 2011, Schaal *et al*, 2014) or provide objective data to verify perceptions of poor sleep and under-recovery, a need to capture baseline data and verify athlete self-reported sleep issues. Regardless, as practitioners, we can be more proactive than reactive and, by collating baseline data on athletes' objective and subjective sleep and/or movement behaviour, means we can potentially foresee issues relating to fatigue management.

Having said that, introducing fatigue management assessment is a change in standard practice, given Sports Science practitioners have conventionally employed a standard battery of assessments to characterise and measure athlete adaptation and recovery from training. Introducing fatigue management assessment displays a variance to exercise physiologists' philosophy to fitness assessment battery. To date, sleep and associated movement behaviour have not traditionally been part of this assessment battery, yet, as I will describe in Chapter 3, sleep is a physiological process which the applied physiologist should feel compelled to profile in an elite athlete. The challenge is that whilst the mystery of sleep has been investigated since the early twentieth century (Piéron, 1913), little research had been completed in the Sports Science industry, in relation to sleep and its effects on athletic performance or vice versa (refer to Chapter 4). Despite being a physiological process (refer to Chapter 3), sleep falls primarily into the domains of psychology, neuropsychology, cardio-respiratory medicine and chronobiology (biological rhythms). The mystification of the essence of ‘sleep’ and the combination of science and medical fact mean that, in academic terms, no single discipline ‘owns’ sleep and it therefore is examined within multiple academic fields. Nevertheless, despite the relationship between sleep and numerous academic domains, the concept of fatigue management through sleep and associated movement behaviour assessment, has not been high on the agenda of most contemporary sleep research groups, with research outputs claiming ‘loose’ associations between sleep and recovery and I shall elaborate further on this discussion in Chapter 4.

Nonetheless fatigue management, through sleep and associated movement behaviour assessment, are important variables for a physiologist to consider measuring with their athlete cohort. Not only does this provide more quantitative information for the coaching and science and medicine team supporting the athlete, but also requires a sense of empathy towards the client (the athlete) and this ability to create trust, credibility and hold an honest dialogue with the athlete is a skill set demanding more attention from developing practitioners. These are a principle points which will recur throughout the thesis.

1.6 Summary

This chapter has aimed to summarise the purpose of the thesis and, to provide some context to the UK high-performance sport industry, and myself as a practitioner in it. I have highlighted my positionality as a practitioner in the UK high performance sport system from neophyte student to a leadership role within the EIS and more recently, a freelance performance consultant, specialising in the area of high performance sport and sleep. Parallel to this professional advancement was my personal development and desire to work in a different form within the UK high performance sport industry. During the time frame of my professional doctorate I have transferred from a full-time practitioner in a medal winning sport, to focusing on a leadership and management role, whilst growing my family (becoming a wife and mother) and transitioning into my most recent consultancy role.

Finally, this chapter takes the reader towards the reasons why a concept such as fatigue management should be introduced to the UK high performance sport industry. A further description of why this should be considered and the process of inception of the initial idea through to current day activities are provided in Chapters 4 and 6.

The next Chapter will focus on ethics and also for purposes of clarity, include a definition of 'eliteness'. Correspondingly it will outline the qualitative methodology which was utilised to provide context, illustration, depth and content around the quantitative findings and it is hoped, ultimately enrich the thesis. As described in the Chapter Sequence, this will then be followed by a Chapter focusing on a technical description of sleep and movement behaviour in order to establish what these impact factors are ahead of any further discussion.

Chapter 2. Qualitative Methodology

2.1 Introduction: why a qualitative methods approach?

Whilst the majority of projects reported in this professional doctorate will follow a quantitative methodology, there is scope for qualitative methods to supplement the quantitative studies and add substance to the overall discussion. For the overall thesis, a mixed methods design was employed to capture all the relevant data. The quantitative methodology is presented in Chapter 5. In this chapter, following information regarding ethics and, for purposes of clarity, a definition of 'eliteness', the qualitative methodology is presented. The principle justification for this approach was that, through qualitative methods, there were opportunities by which purposely selected individuals provided depth and context through representations in the form of verbatim quotes and constructed narratives regarding the introduction of the concept of sleep and movement behaviour in UK high performance sport.

2.2 Ethics

For all aspects of the study, qualitative and quantitative methods, ethical committee approval has been obtained from the University of Kent, School of Sport and Exercise Science (July 2014, Appendix 1). All participants signed an informed consent form (Appendix 1) prior to any data collection being undertaken. Where repeat testing or monitoring procedures were performed, participants were asked to provide further informed consent only if their circumstances have changed e.g. injury. This is in conjunction with Winter and Maughan's (2009) suggestion that types of functional capability tests may be a requirement of employees such as athletes in National Lottery funded sports programmes. All data is protected under the 1998 Data Protection Act.

2.3 Defining 'eliteness'

There has been inconsistency within the Sports Science and Medicine literature as to what defines an 'elite' athlete. Nevertheless, for this thesis, it was imperative that it was determined from the outset what the term 'elite' means in this high performance sport context. Using a method to define a model for 'Classifying the Validity of Expert Samples in Sport' (CVESS) (Swann *et al.*, 2015), the 'eliteness' of the athletes in this study is confirmed as 'world class'. In this model, athletes are assessed against set criteria relating to 1) within and 2) between-sport criteria. Within-sport comparisons are broken down to an evaluation of the participant's level of performance; the success achieved and the experience at that level; and between-sport comparisons include competitiveness of the participant's sport both on a national and global scale. Each individual component is ranked on a scale (score range 1-4, where 4 is elite) and computed. The outcome of this model is a quantifiable continuum of 'athlete eliteness': semi-elite; competitive elite; successful elite and world class elite (score range 1-16) (Gupta *et al.*, 2016). Figure 2.1 displays the equation for the classification system of eliteness according to Swann *et al.* (2015) and should be utilised with Table 2.1 which outlines their classification model.

Eliteness/expertise of athletic sample = [(A + B + C/2)/3] x [D + E)/2]

Figure 2.1 Equation and classification system of eliteness according to Swann *et al.* (2015)
Classification: 1-4 = semi elite; 4-8 = competitive elite; 8-12 = successful elite; 12-16 = world class athlete

Table 2.1 Model for classifying the validity of expert samples in sports science research (Swann *et al.*, 2015).

Variable/Score	1	2	3	4	
A Athletes highest standard of performance	Regional level; university level; semi-professional; 4th tier leagues or tours	Involved in talent development, 3rd tier professional leagues or tours	National level; selected to represent nation; 2nd tier professional leagues or tours	International level; top tier professional leagues or tours	**Within-sport comparison**
B Success at the athletes' highest level	Success at regional, university, semi-professional or 3rd/4th tier	National titles or success at 2nd/3rd tier	Infrequent success at international level or top tier	Sustained success in major international, globally recognised competition	
C Experience at the athlete's highest level	<2 years	2-5 years	5-8 years	8+ years	
D Competitiveness of sport in athletes' country	Sport ranks outside top 10 in country; small sporting nation	Sport ranks 5-10 in country; small-medium sporting nation	Sport ranks top 5 in country; medium large sporting nation	National sport; large sporting nation	**Between-sport comparison**
E Global competitiveness of sport	Not Olympic sport; world championships limited to a few countries; limited national TV audience	Occasional Olympic sport; world championships limited to a few countries; limited international TV audience	Recent Olympic sport with regular international competition; semi-global TV audience	Regular Olympic sport with frequent major international competition; global TV audience	

2.4 Qualitative methodology

The aim of this section is to report on a qualitative study to explore the perceived impact of evolving the new concept of fatigue management to the high-performance sport industry. This line of enquiry is incorporated within some of the aims of the professional doctorate, namely; to ascertain the growth of sports science over the last 20 years and how fatigue management has emerged as part of the industry development. Fundamentally, the research was undertaken to determine *why* physiologists should take responsibility for sleep and athletic performance measurement and assessment. Further, the research methodology would allow articulation of examples of fatigue management projects in high performance sport, explore methods of optimal practice for assessment of fatigue management and enable recommendations for future research and applied practice in relation to fatigue management of elite athletes. The qualitative methodology also assisted in encapsulating and understanding the impact of introducing the concept of fatigue management to the UK high performance sport industry better than my personal observations alone. Finally, it helped to provide justification for investigating the area of fatigue management in high performance sport and the process and success of introducing it as a concept to other practitioners within the UK high performance sport system.

Qualitative methodology has gained increasing popularity across the sport and exercise domain in recent years with the acceptance of the value that a single or variety of qualitative research methods can achieve to explore phenomena. The use of qualitative methods in mixed methodological approaches can elicit depth and context from that acquired through quantitative data. The emergence of a peer reviewed journal, *Qualitative Research in Sport, Exercise and Health* (Taylor and Francis Group) is perhaps alone indicative of the development of this methodological 'shift' (Culver *et al.* 2012, Culver *et al.*, 2003, Biddle *et al.*, 2001). Qualitative methodologies provide a more holistic and naturalistic enquiry. They provide purposeful perspective from individual and personal insights, are process driven and are more flexible in design. (Patton 1990). Qualitative methods are diverse from that of single interviews focus groups (Patton 1990) and participant observation (Tedlock, 1991), to that of creative means such as photo-storytelling (Clark & Moss, 2011) or write and draw (Parnell *et* *al.*, 2013). However, the 'interview' format remains perhaps the most fundamental and common data collection technique in this research domain (Thomas and Nelson, 1996, Halcomb and Davidson, 2006, Culver *et al.*, 2012).

> ''interviews have been widely accepted as a common means of data collection in a range of disciplines allied to that of the sport and exercise science, including nursing, sociology, social work, and health, principally because of the required interaction between interviewer and interviewed''. Halcomb and Davidson (2006 pp.38)

To ensure effective preparation and required knowledge of the subject area and participants, the methodology was inspired by informal conversations with peers within the UK high performance sport industry and review through academic sources, colleagues and literature associated with both qualitative methods and sleep and movement behaviour. This methodological development phase took place over a long period of time as I was gathering my thoughts on how to display the impact of the evolution of the concept of fatigue management to the UK high performance sport industry. Further, this 'reconnaissance phase' also considered recruitment and development of the interview guide as the instrument tool. In all, this phase of methodological development, planning and delivery took 18 months, with the initial informal conversations having the impact of ensuring I was proactive in making the qualitative aspect of the thesis come to life.

Peer support and technical advice was sought from a Health and Care Professions Council Registered Practitioner Psychologist (sport and exercise) (HCPC) with regards to exploring the paradigmatic location of this research and methods of analysis on the basis of what the study was to achieve through exploration of realities. The psychologist had no previous experience as regards the topic area and had never worked directly with the EIS by virtue of employment or role but had extensive experience of working with elite athletes as a consultant.

Having traditionally resonated with a more quantitative approach, I explored the ontology[4], epistemology and methodological approaches associated with the qualitative paradigm relative to its inclusion in the thesis. This process involved considering what the research was attempting to understand (individual compared to social realities), being conscientious of trustworthiness and deciding on the type of instrument/s to utilise.

2.4.1 Rationale

In order to encapsulate and understand the impact of introducing the concept of sleep and movement behaviour into the UK high performance sport system, a qualitative, formative research design was employed. Here, the specific aims were firstly to generate a purposeful sample of those identified key UK high performance sport industry personnel who had been involved in sleep and waking movement behaviour projects. Secondly, on participant consent, the interview aimed to explore the perceived impact of evolving sleep and movement behaviour measurement and analysis in the UK high-performance sport industry. Thirdly, to understand the participants' awareness of such projects e.g. knowledge of implementation of such projects and their professional knowledge gained from them. Finally, the interview aimed to discuss participants' ideas for future initiatives around sleep and movement behaviour measurement and analysis and explore any barriers and facilitators.

[4] Ontology is the branch of metaphysics dealing with the nature of being whilst 'epistomology' is the theory of knowledge, especially with regard to its methods, validity, and scope, and the distinction between justified belief and opinion (The Oxford Dictionary, 2014)

2.4.2 Research questions

Given the identified aims listed above, specific research questions were organised across five sections outlined in Table 2.2.

Table 2.2 An outline of the interview guide structure

Section	Detail
1. Introduction	• Introducing the rationale for the interview and to offer an explanation as to why the participant had been initially identified through study inclusion criteria and that they felt this was appropriate and still offered voluntary consent. An outline of the interview and a reiteration of anonymity and right to withdraw at any time without the need for explanation were also provided.
2. Conceptual	• Outlining the concept behind analysing sleep and movement behaviour in high performance sport
3. Involvement	• Establishing the participant’s involvement in the process of introducing sleep and movement behaviour to UK high performance sport.
4. Understanding	• Tracking the participant’s understanding of the introduction of sleep and movement behaviour into the UK high performance sport industry and any perceived impact it may have had.
5. Evaluation	• Allowed the participant to offer any challenges that they may have faced and to evaluate the process of introducing sleep and activity analysis to the high performance sport industry. It was recognised that the participant’s responses in this section may well inform future directions as to where research can be targeted in the next Olympic cycle.
6. Closure	• Opportunity to thank the interviewee for participation, allow any questions or topics to be raised not covered in interview and explain what happens next in terms of data protection, transcription and availability of the interview for their reference if required.

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2.4.3 Participants

Five participants (male n = 3 age 41 ± 15 yrs.) were purposely selected for the interviews. Average experience in high performance sport was 9.4 ± 6.7 yrs. and average experience in sleep academia was 10.6 ± 11.3 yrs. Table 2.3 provides an overview of each of the participants.

Table 2.3 Background information of participants for interviews

Participant	Role and responsibilities	Experience in high performance sport (years)	Experience in using sleep assessment (years)
1	• Physiologist to an Olympic combat sport. • Responsible for the physiological preparation of high performance boxers in preparation for international competition.	6	3
2	• Performance lead for the English Institute of Sport. • Responsible for enabling sports to define their performance questions that have clear alignment to 'What it Takes to Win' (WITTW), or what's needed to win their sport. This includes: • Enabling sports to define, review and evolve the WITTW process and facilitating performance planning and debriefing with coaches and sports science and sports medicine (SSSM) practitioners. They also support and enable the alignment of SSSM, technology, system and stakeholder support to what's needed to win. • Also, co-ordinate and share practice from and within the high performance sports system. • They are the main point of contact within the English Institute of Sport to align practitioners' work flows, key projects and personnel within the EIS to meet the performance questions as	12	11

	outlined to our 'What it Takes to Win' process.		
3	• EIS PhD student with the English Institute of Sport. • Responsible for the pursuit, investigation and dissemination of research findings in relation to sleep and athletic performance. It involves: • Assessing, monitoring and intervening with athlete sleep (all sports) • Conducting applied research into 'predispositions to sleep disruption in team sport athletes' • Attend international conferences to present findings on sleep	5	3
4	• Director of Loughborough Psychology, overseeing the delivery of 5 Psychology programmes across 3 Schools. • Director of the Clinical Sleep Research Unit: the development of applied sleep research in clinical areas, and the use of health technologies to improve sleep quality. • Professor of Psychology: general academic/pastoral duties • Over 30 years' experience in experimental and applied sleep research, and pharmacological and psychological research.	4	30
5	• Chief Medical Officer for a successful Olympic and Paralympic team • Responsible for the health and wellbeing of Olympic and Paralympic athletes in their sport	20	6

A method of triangulation was employed throughout the process, from instrument design to analysis, which was undertaken with my professional doctorate supervisor and also a Health and Care Professions Council Registered sport and exercise psychologist. The psychologist also helped to support the process of adopting a qualitative paradigm as part of my thesis and subsequent methodological decision-making through a series of consultations.

Potential participants were identified as meeting inclusion criteria and therefore eligible based on their experience of fatigue management practices in high performance sport, either directly through work within the EIS or external to EIS workflows and their level of persistent observation with myself. Inclusion criteria was established as;

1. Participants had to either be a practitioner, coach or athlete within or a research associate of the UK high performance sport industry.
2. Participants would have at least three years' experience in their respective roles
3. Participants would have been involved in the UK high performance sport system in either or both the London and Rio Olympic cycles (2008-2017).

The limited sample population was justified as it provided comparable insights into the impact of the introduction of sleep and movement behaviour analysis in the UK high performance sport system by individuals who had direct or indirect involvement of its use during the period (2008-2017). This process was given credibility through peer debriefing with my professional doctorate supervisors.

2.4.4 Ethical compliance

Through the initial research proposal, ethical consent was applied for and received for the qualitative part of the thesis from the University of Kent (2014) (Appendix 1).

2.5 Research protocol

2.5.1 Instrument development

A single semi structured interview was used and has been demonstrated to provide reliable, comparable qualitative data (Cohen & Crabtree 2006). Semi structured interviews were designed to last approximately 60 minutes and provided an opportunity for pre-determined questions to be asked and also allow the interviewer to follow topical trajectories in the conversation that may stray from the guide when appropriate. Importantly, participants were given the freedom to express their views in their own terms with opportunity for deviation and exploration of relevant topics aligned to research questions (appendix 2). In short, this format facilitated comparison across participants whilst still allowing flexibility in participant responses (Hardy *et al.* 1996).

In shaping the research instrument, I received intensive technical counsel, direction and methodological guidance from an external advisor (a Health and Care Professions Council Registered sport and exercise psychologist), both pre- and post-interviews. Specifically, advice was provided on the thematic (question construction) and dynamic (organisation of question order, participant motivation, listening and responding skills and interview flow) aspects of the interview and data handling/representation. Further, there were checks made to ensure alignment of the interview questions to that of the overall study aims by reverse tracking. This process of peer debriefing, not only upskilled myself as interviewer in qualitative methods, but also ensured dependability criteria was achieved for guaranteeing the trustworthiness of the data to be collected.

2.5.2 Pilot

A principle benefit to using a semi structured interview process was that questions could be prepared ahead of time, allowing me to be prepared and competent as regards directing questions and responding appropriately during the interview. As part of this research and instrument development process, a pilot interview was conducted with a suitably qualified individual from the UK high performance sport industry. This allowed rehearsal of semi structured interview techniques, enhanced my ability in asking questions, listening, building trust and rapport with the participant and achieving the expected outcomes from the interview schedule.

Assessing the pilot interview ensured several trustworthiness criteria were achieved, such as credibility through triangulation (refinement of the interview guide) and peer debriefing (were questions were of suitable clarity, purpose and rigour and eliminated any bias in the process). Further trustworthiness criteria verified were; member checking through seeking feedback from the pilot interview participant in terms of how they felt during the interview and the phraseology used and the structure of the process. Credibility was achieved through referential adequacy (data was recorded so others could check its accuracy), dependability and conceivability techniques. Dependability was sought through my demonstrated knowledge and competence as a practitioner in the topic area of the interview and in the high-performance sport industry. Further dependability was shown through my seeking of training and advice in the chosen qualitative research technique. Finally, in preparation for any external checks being requested, conceivability was achieved through an audit trail of the process including participant selection, interview guide planning, data collection, transcription and analysis.

The pilot process allowed practice of skills in maintaining objectivity, thereby sustaining perspective on the knowledge obtained from the interviews and avoiding over-identification with the participants. With such familiarity there is potential for some bias and contention, however, this was limited through pilot interview techniques being reviewed by an experienced qualitative researcher and HCPC Registered Practitioner Psychologist.

2.5.3 Development of interview guide

Trustworthiness was also demonstrated through credibility criteria such as prolonged engagement with the high-performance sport industry and relationship with those interviewed. This ensured the interview guide was structured via sections and included only questions which were pertinent to the research aims and succinct so as not to over burden participants. Strategies to deal with incidences whereby the trajectories of the conversation became irrelevant were discussed.

Peer debriefing occurred through the development process whereby I had multiple drafts of the interview guide verified against the research questions by my professional doctorate supervisor and also a Health and Care Professions Council sport and exercise psychologist who also checked for appropriateness, coercion and leading questions and which occurred to the point of full consensus from within the supervision team.

To ensure flow through the interview guide, I was in a position through persistent observations to build rapport, establish trust and acceptance from the participants quickly. In acknowledging by doing so this could potentially introduce bias, there were measures in place to ensure this was not ‘skewed’ or ‘leading’. This trust could not have been achieved had I not been a well-established practitioner within the UK high performance sport system having had experience of multiple Olympic and Paralympic cycles. Such prolonged engagement both with the participants and knowledge of the cultural context for the interviews, (i.e. industry familiarity, understanding and experience), ensured I aimed to understand and clarify the meanings and interpretations each participant offered rather than probing for information or suggesting ideas. This, along with persistent observations of the chosen participants in their fields of work, added to the research trustworthiness credibility criteria. Therefore, rapport was gained through familiarity of environment and industry with the interviewees and my experience in the field of high performance sport.

2.5.4 Interview protocol

Informed consent was obtained via a pre-prepared written informed consent form and a letter was sent to participants prior to the interview taking place (Appendix 1). These documents contained a summary of the aims of the professional doctorate, reasons for the scheduled interview and the participants' involvement. Benefits and risks to the participants contributing to the study were also outlined. Confidentiality was assured for all aspects of the professional doctorate. Specifically, for the semi structured interviews, participants were given an ID for anonymity purposes with confidentiality maintained through anonymising the responses from the participants.

As principle researcher, I was the sole conductor of the interviews which were conducted face to face in a private consultation room at a location most suited to the participant. There was also an agreement for a follow up post interview either in person or remotely to clarify details or investigate further points made.

Referential adequacy was achieved through recording and verbatim transcription of interviews. Recording was achieved using a digital voice recorder (Allreli, China) which was checked operationally by me during the preliminary stages of the interview.

Open-ended questions were asked in the same order and guided the interviews. Throughout each interview as part of a member checking process as responses were gathered, I paraphrased and probed to ensure my understanding of participant meaning and challenge my assumptions. These probes elicited rich details and descriptions/examples and helped me learn why observations were important to participants (e.g. "What was significant or important to you about [that observation]?").

At the end of each event interview, I asked for any other information that the participants felt were relevant to the topic (Isabella 1990). Whilst each interview used the same research questions, I aimed to maintain the ability to explore areas of individual significance to a participant in depth and understand the frames of reference each participant offered.

To ensure honesty, I followed guidance by Knowles (personal communication, 2016) in that 'throughout the research process I sought to achieve a fair and trusting relationship with participants, enhancing the authenticity of our shared interview experience. If a participant was not comfortable answering a question, they were not required to do so'.

2.5.5 Data handling and representation

Once the interview was complete, the audio files were downloaded onto an English Institute of Sport (EIS) encrypted laptop (MacBook Pro) and deleted from the Dictaphone. The EIS laptop was password protected and had sole use by me. I also underwent training in data protection through the English Institute of Sport by EduCare®.

All interviews were then sent via a secure online transfer programme (https://www.wetransfer.com/) to an external transcriber who had relevant policies and practices in place to ensure compliance with data protection. The interviews were then transcribed verbatim with identifying characteristics of the participants. Transcriptions were saved as a PDF file and emailed to the participants post interview to allow them to sense check the contents of the transcript. This member checking helped to ensure accuracy, credibility, validity, and applicability of the process and build trustworthiness on the part of the principal researcher prior to interviews. All data was stored on an EIS encrypted laptop and according to the 1998 Data Protection Act. I was the custodian of the data.

Conceivability and dependability were achieved through the processes of informed consent, recorded interview and transcription. This ensured a detailed audit trail for those wishing to inspect findings or replicate, and complied with the trustworthiness of the research process. Due to the anticipated low subject number due to inclusion criteria, analysis was deemed inappropriate and therefore representation by verbatim quotes was employed. Interviews lasted on average 51 (±21) minutes. Extracted quotes which could be interpolated throughout the thesis text to add context, depth and insight were used to explore the impact of analysing sleep and waking movement behaviour in high performance sport. This transferability through providing thick descriptions (quotes from the participants) throughout the thesis also enriched the study's trustworthiness.

Answering one of the study aims of what had been the ‘impact’ of evolving the concept of sleep and movement behaviour measurement and analysis into the UK high performance sport industry led the extraction of quotes. Simply, this process enabled me to efficiently retrieve and collect together all the transcribed text that I had collated and offer illustrative quotes at relevant points in the final thesis text to illuminate the answers to the research questions, offer examples of agreement/disagreement and highlight examples/practicalities of implementation/challenges. Therefore, the qualitative data sought to provide ‘true’ and definitive insights into the impact of the evolution of sleep and movement behaviour into the UK high-performance sport industry.

To clarify, the results from this short study are not presented in a specific independent section. The verbatim quotes appear in the successive Chapters where necessary, principally in Chapter 7, where they add context to the described impact and future directions in evolving the concept of fatigue management.

The following Chapter will focus on a technical description of sleep. It will provide an outline of the physiological processes of sleep, provide information on the architecture of sleep and why and how it is an important entity to be considered by physiologists working with high performance athletes and coaches. A description of movement behaviour is also provided.

Chapter 3: A Technical Description of Sleep and Movement Behaviour

3.1 Introduction

Chapter 1 presented the evolution of the UK high performance sport industry with a traditionally amateur approach to sporting success exchanged for high end business approaches aimed at establishing 'What it Takes to Win' models for all Olympic and Paralympic sports. In line with the 'What it Takes to Win' models were impact factors on such winning variables. Sleep and movement behaviour, collectively termed as fatigue management were two of these performance influencers. The thesis highlights data I have gathered from elite athletes on their sleep and movement behaviour. The motivations for gathering such data were to help inform athletes, coaches and support staff to understand compromised athletic recovery practices, educate athletes on the importance of good generic recovery choices and also provide normative data on a previously unknown entity. From analysis of this data I made recommendations to the UK high-performance sport system on areas where athletes felt compromised in their 'downtime', e.g. extra curricula activities outside the training programme. As such, I feel it is pertinent that I provide a description of what sleep and movement behaviour are ahead of further presentation of data in the thesis. In doing so, I should point out that my intention is to provide information on sleep and movement behaviour as I would to a coach or fellow practitioner (i.e. relevant points and papers), and not a definitive review on sleep and movement behaviour.

This chapter is therefore a review of the sleep and associated movement behaviour literature and the perspectives I have developed through my work on what I collectively term 'fatigue management'. I see it also as a review of the relevant points I try to share with colleagues who want to support their athletes in the fatigue management domain.

Specifically, in terms of sleep, I believe in order to grasp the concept of what 'sleep' is and explore my idea of introducing the concept to the UK high performance sport industry through the umbrella term of fatigue management, necessitates a rudimentary understanding of sleep without a detailed neuroscientific, or more specifically, neurophysiological, explanation. Therefore, I feel a detailed neurophysiological description of sleep is not relevant to the thesis and beyond the scope of this chapter. For reference the reader is directed to Harris, 2006 and Dick & Feng, 2014. What I present in this chapter, (and also in Chapter 4), are my perspectives on fatigue management and athletic performance. These perspectives are reinforced through highlighting salient points and papers within the current academic literature.

Whilst this thesis explores generically the concept of fatigue management, in this chapter I shall firstly, specifically focus on the 'sleep' aspect, where I will provide a rudimentary description of sleep. I will endeavour to include an explanation of what we mean by sleep quality and the physiological processes and purpose of sleep through presentation of the scientific description of sleep, its regulation and architecture. Secondly, more detail on movement behaviour; what it is and how it is of relevance to the remainder of the thesis will be provided.

3.2 What is sleep?

Whilst much is known about the mysteries of the human body and its biological functioning, the exact mechanisms for sleep, its true function and the reason we as a species need it and with such regularity, remain unknown. Sleep has been studied since the early 20th century

(Piéron, 1913)[5] and contemporary interest in sleep research is performed in a multitude of academic domains, for example; physiology, psychology, neuropsychology, cardio-respiratory medicine and chronobiology (biological rhythms) (Xie *et al.*, 2013, Nunn *et al.*, 2016). Generally, sleep research in these areas focuses on poor sleep quality and problems associated with sleep deprivation, e.g. through hypoxia induced sleep apnoea or more significant clinical insomnia. In general terms, sleep deprivation induces sleepiness and reduces daytime alertness and performance (Leger *et al.*, 2008). Specifically, how athletic sleep is deprived and its effects on athletic performance or vice versa needs addressing in more detail in the contemporary Sports Science literature and I shall endeavour to explain later in Chapter 4 what has been reported to date. For the purposes of clarity, I will principally focus on the studies that have been conducted up until 2017.

In terms of sleep and its general purpose, numerous theories exist mainly related to physical and psychological recovery and restoration. For example, some theories purport that it helps with energy conservation (Schwartz and Roth 2008), memory consolidation, cerebral growth and metabolic clearance (Xie *et al.* (2013), immune system maintenance, muscle restoration (Takahashi *et al.* 1968, Besedovsky *et al.*, 2012) and a discharge of emotions (Samules, 2008, Myllymaki *et al.* 2011, Venter, 2012). Although, whilst generically sleep is understood to be restorative, what precisely is being restored is uncertain (Schwartz & Roth, 2008). Whilst links have been made to sleep and the body's homeostatic mechanisms and circadian rhythms

[5] The history of sleep research started in 1913 when Henri Pieron, a French Scientist, wrote a book called "Le probleme physiologique du sommeil." This book was the first where sleep was analyzed from a physiological perspective. Since its publication, this work book is treated as the beginning of the era of the modern sleep research.

(Borbely *et al.*, 1982), the very reason for sleep remains unclear. Determining the function of sleep is therefore one of the biggest unsolved scientific questions (Frank & Benington, 2005).

In a wider media context, sleep tends to be reported as a mystery life occurrence to which we know little about its purpose and meaning. Contemporary research into sleep often surfaces in the media, making sleep a societal issue which never seems to fade from interest whether it is in relation to the basic mystery of sleep, sleep deprivation or its potential links to mental health illness. Sleep is often presented in the media with negative connotations, i.e. the limitations of having 'poor sleep' or the pressures of modern life being why we have 'poor sleep'. Czeisler & Fryer (2006) reported that in today's society the need to work long hours (e.g. 100+ hour work weeks) and frequent crossing of multiple time zones is the kind of corporate behaviour that is the antithesis of high performance. Bravado reported in the media from individuals claiming to need little sleep, e.g. Margaret Thatcher famously had impressive indefatigability, exacerbates the myth that the less sleep you need the more efficient an individual you are. Unfortunately, this is not the biological case and it is here the media can be guilty of sensationalising stories for journalistic gain.

What we do know is that sleep is governed by biological processes and it is a primal need without which we would perish. Described as a reoccurring habitual event of intervals throughout a 24-hour period, sleep is a homeostatically controlled behavioural state of reduced movement and sensory responsiveness (Fullagar, 2015). The individualised nature of sleep and the disparity between an individual's sleep requirements mean the value of sleep can be underestimated, yet it is a diurnal function which we all require.

Further evidence of this came from my own professional experience with an elite rower who devalued sleep and 'downtime' in favour of earning extra money from coaching club rowers late into the evenings. This had a concomitant effect on their ability to consistently deliver quality training sessions with the British Rowing squad, and their performances decreased. Through actigraphy analysis (described in Chapter 5) we were able to display the discrepancies in the rower's fatigue management strategies, and following changes to their club coaching schedule, we ensured their sleep and downtime were protected. Consequently, their performances in training improved.

A notable researcher in sleep, Borbely *et al.*, (2016), stated, sleep must ''subserve long term maintenance of cerebral integrity''. It is the plasticity of the brain which causes the demand for sleep in that the synaptic and cellular processes that have been challenged during waking are re-established during sleep. Sleep therefore is a period of restorative responsiveness of which the dynamic processes governing it intrinsically interact (Morgan, 2016). In essence, the exact reason for sleep is that it is considered critical to human physiological and cognitive function (Fullagar *et al.*, 2015) and it is more likely that it has a multi-purpose role for restorative, neuro-metabolic and cognitive benefits than a single biological purpose (Frank & Benington, 2006).

The simple truth is that sleep is an individual process and whilst we remain mystified in modern medicine and science as to its exact function and reason, we know that we need it, everyone does it and without it we would die. It is therefore arrogant to assume that we can defy evolution and thrive on shorter, disturbed rest (Wallop, 2014).

3.3 Sleep regulation

Given sleep's significance to sustaining basic human life, it is important to understand how it is regulated. One should consider that sleep is a process involving several biological factors; homeostatic drive, neurophysiological control and an element of automaticity. How these elements all interact influences the regulation of sleep. All three components shall be outlined as follows.

Borbely's (1982) two-part model of sleep is widely regarded as the most influential theory as to the regulation of the evolutionary conserved behavioral state of sleep (Gandhi *et al.*, 2015). Simply, it states the regulatory homeostatic drive for sleep (sleep-wake Process S) and the body's circadian rhythm (Process C) are interdependent on each other. The model hypothesised how sleep regulation is achieved through a homeostatic process (Process S) responding to internal cues for sleep need and a circadian process (Process C) that responds to external cues. That is, the model involves an arousal system which promotes wakefulness and when its processes are inhibited it promotes sleep, this is summarised later in this chapter.

3.3.1 Homeostasis and sleep

Fullagar (2015) stated sleep is a homeostatically controlled behavioural state of reduced movement and sensory responsiveness. That is, the longer we are in a state of wakefulness, the drive to maintain the body's homeostatic (balanced) state is enhanced and homeostatic pressure to fall asleep increases. Otherwise known as 'sleep pressure', this pressure increases linearly the longer we are awake and then decreases during sleep. Therefore, homeostasis allows the body to return to equilibrium when it has been disturbed (Schwartz & Roth, 2008).

Note, disturbances can be identified as any form of stresses on the body but in the high-performance sport domain (and for this thesis) I will relate to any stress on the body as being the physiological, psychological or environmental stressors of athletic training and competition.

3.3.2 Circadian rhythm and sleep

The human race operates on a 24-hour cycle known as the circadian rhythm. It responds to external cues, e.g. cycles of light and dark over a 24-hour period and is in addition to the aforementioned body's internal drive to maintain homeostasis. Many aspects of human biology have a circadian rhythm but Besedovsky *et al.* (2012) reported the sleep-wake cycle as being the most ''prominent manifestation of the circadian rhythm'' (Besedovsky *et al.*, 2012, pp.124). Similarly, Borbely *et al.* (2016), reported ''by enforcing quiescence and fasting, sleep ensures optimal physiological and behavioural conditions for restorative peripheral metabolic processes to occur. In this respect sleep is an adjunct of the 24-hour cycle of metabolism'' (Borbely *et al.*, 2016, pp. 136).

The process aiding the circadian rhythm associated with light and dark is governed through the hypothalamic pacemaker known as the suprachiasmic nucleus (SCN). This biological component ensures synchronicity of any cellular oscillating rhythm. Essentially light and dark cues are signaled through the retina which houses specialised photosensitive cells that send signals via the retinohypothalamic tract to the SCN. The circadian rhythm uses external cues from the optical photosensitive light receptors in the eye which filter light through to the SCN in the hypothalamus and work in conjunction with the body's ascending arousal system (more detail further in this chapter) to ensure sleep and wakefulness occur in response to such light and dark cues. This sends a cascade system into play which signals the endocrine system to relay several different hormones into action and signal pending sleep in response to dark.

3.3.3 Arousal systems

The essence of the aforementioned Borbely's (1982) two-part model of sleep is, firstly, the 'ascending arousal system' (AAS) and, secondly, its interaction with the sleep inducing ventrolateral preoptic nucleus (VLPO); the former governing wakefulness, the latter responding to sleep cues. The AAS has a subcortical neural circuitry which is discrete, yet interdependent, on the circuitry for wakefulness and is therefore critical to consciousness. The AAS includes numerous neurons e.g. cholinergic, noradrenergic, serotoninergic, dopaminergic, and histaminergic, which are located in the upper brain stem near the junction of the pons and the midbrain. Projections from these various cell groups fire in a characteristic pattern to promote arousal. The AAS neurons project and connect the brainstem to the thalamus, hypothalamus, basal forebrain and cortex, activating cortically based awareness networks. It promotes wakefulness through these various projections, each with distinct neuro components which characteristically 'fire' when homoeostatic and circadian drive dictate wakefulness (Schwartz and Roth, 2008). The AAS is inhibited by sleep promoting neurons every 24 hours from the VLPO, which is small cluster of neurons situated in the anterior hypothalamus. Facilitators of the VLPO are several but, predominantly, it is activated by the sleep inducing neurotransmitters serotonin and adenosine. Conversely the VLPO is inhibited during wakefulness by the arousal-inducing neurotransmitters noradrenaline and acetylcholine. It is the interaction between the VLPO and the AAS pathway which acts like an 'on-off' switch for sleep, thus enabling the body to maintain a homeostatic state. The abrupt nature of the transition between sleep and wakefulness is linked to the reciprocal inhibitory exchange between the AAS and sleep inducing VLPO. This exchange acts as a feedback loop and is described, in electrical circuitry terminology, as a bistable 'flip-flop' circuit in which the two halves strongly inhibit one another, i.e. are either 'on' or 'off', thus changes are infrequent and rapid. It is the design of this 'flip-flop' switch which ensures stability between sleep and wakefulness while promoting rapid transitioning between the two behavioral states (Schwartz & Roth, 2008). In essence sleep regulation involves the rapid 'flip-flop' action of the transition between sleep and wakefulness and it is the action of the VLPO which promotes sleep through its inhibition of the AAS. Put simply, information passes continuously between the sleep–wake-dependent and circadian processes outlined which are subject to more complex interactions (beyond the scope of this chapter) and account for the essential aspects of sleep regulation (Borberly *et al.*, 2016). In essence, our basic human tendency to sleep is determined by the time passed since the previous sleep episode (homeostatic drive) and time of day (circadian drive) (Thun *et al.*, 2015).

Corresponding with this interconnecting system of neural circuitry and homeostatic and circadian rhythm is an endocrine element. Located in the pineal gland, the hormone melatonin is a principle molecule in this sleep signaling process. Melatonin essentially inhibits the circadian drive for wakefulness. It is released in the evening via stimulation from the SCN and interacts with the previously described sleep regulatory systems to ensure sleep ensues.

In summary, sleep involves the bodies need to maintain a finite equilibrium, its responses to biological rhythms and a distinct and overriding electrophysiological structure. With its unique circuitry deep in the brain, the neurophysiology of sleep is the driving force behind the regulation of sleep and wakefulness.

3.3.4 Automaticity

It is from such physiological processes as homeostasis, circadian drive and neurophysiological circuitry that we can state sleep is dominated by a physiological impetus. Yet it has a strong psychological component, known as automaticity, making the case that sleep is a psycho-physiological process.

Automaticity reinforces the notion that those who are good sleepers do not necessarily know how they do it or why, ensuring good sleep is not an issue for them. Sleep for these people is, in its normalcy, an automatic process, occurring involuntarily in a well-adjusted sleep schedule. For these people, sleep requires no effort and occurs passively with persistent regularity (Broomfield *et al.*, 2006). Where this gets interrupted or navigated away from its natural automated mode, a psychophysiological insomnia (PI) condition can be said to ensue (Broomfield *et al.*, 2006). Here sleep becomes the 'attention focus' and whilst sleep is important to those suffering psychophysiological insomnia, it becomes less achievable as the person places excessive focus on and experiences heightened anxiety about sleep (Broomfield *et al.*, 2006).

3.3.5 Sleep quality

Sleep quality (duration) can be characterised as an individual's subjective experience and perceived adequacy of sleep. It typically focuses on problems initiating or maintaining sleep or early morning awakening (Gupta *et al.*, 2016). I will elaborate on its assessment further on in the thesis but in short, it can be assessed through instrumentation or subjective means.

Poor sleep quality or insufficient sleep, i.e. regularly achieving less than 7 hours, is considered a public health concern and it has been identified with associated risk factors for several critical health issues, e.g. obesity, type 2 diabetes and cardiovascular diseases, mental health disorders, immune system dysfunction, a reduction in learning, impaired performance in cognitive tests, prolonged reaction time, dementia and an ultimately overall increased risk of death (Schwartz & Roth, 2008, Besedovsky *et al.*, 2012, Xie *et al.* 2013, the American academy of Sleep Medicine and Sleep Research Society, 2015, Nunn, 2016). Typically, 6-8 hours of sleep per night is recommended to reduce such morbidity and mortality risks (Chennaoui *et al.*, 2015), however, it is widely recognised that sleep duration is a highly individualised requirement which is influenced by genetic, behavioural, medical and environmental factors.

Minimal sleep deprivation results in sleep debt or 'social jet lag', which needs to be managed but is not as devastating as clinical sleep deprivation. Prolonged sleep deprivation is typically termed 'insomnia'. Defined as a persistent difficulty in falling or staying asleep despite adequate opportunity to do so, acute insomnia has been reported to affect approximately 35 % of the UK's general population and can be a debilitating life-long illness.

Insomnia's importance in the context of elite athletes is that it is generally associated with a state of hyper-arousal which involves alterations of the autonomic nervous system, specifically activating the sympathetic drive and inhibiting sleep (Nunn *et al.*, 2016). Whether a person is predisposed to suffering insomnia once subjected to a 'stressful' event can be identified through the Ford Insomnia Response to Stress Test (FIRST) (Drake *et al.*, 2008) which is described in detail in Chapter 5. This is useful to athletic populations as the stressful event can be described as any aspect relating to training i.e. load, volume, intensity, competition, selection etc. and this may in turn be the precursor to an athlete suffering acute insomnia. Indeed, Gupta *et al.* (2016) observed in their review that high performance athletes experience high levels of sleep disturbance, and that such disturbances are characterised by the symptoms of longer sleep latencies, greater sleep fragmentation, non-restorative sleep, and excessive daytime fatigue. Risk factors to this would seem to be competition, travel and training. More detail as to how these factors affect sleep and athletic performance are provided in Chapter 4. Gupta *et al.* (2016) also noted studies of athletic sleep consistently showed 'insomnia grade' sleep latency problems in athletes, yet stated that only three studies reported the prevalence rate for clinical insomnia in athletes (4%), which is within the typical prevalence range of the general population (3-6 % 15-34 year olds in southern Europe). Gupta *et al.* (2016), also suggested the present literature offers no evidence that participation in elite sport improves sleep quality or mitigates insomnia symptomology and that this is similar to findings in other industries such as professional ballet, university students, artists or the military (Gupta *et al.*, 2016). Therefore, there is no definitive judgement on whether elite athletes experience disproportionally higher overall levels of insomnia symptoms for their age and additional controlled comparisons are needed in the Sports Science sleep literature (Gupta *et al.* 2016).

Whilst a detailed description of insomnia is beyond the scope of this thesis, it is important to note that it is sleep deprivation and its association with athletic performance that is the underlying motivation for observing athletes' sleep. Therefore, it is essentially the prevalence of insomnia in the athletic population that we are measuring when conducting sleep assessments in elite athletes alongside the potential to improve individual performance by maximising sleep quantity and quality. It is the relationship between athletic performance and sleep deprivation caused by a myriad of factors which is of interest in Sports Science and sleep academia. This shall be discussed further in Chapter 4.

3.4 Architecture of Sleep

The arousal and sleep systems and their interactions with the body's interdependent circadian rhythm and homeostatic state help to describe what happens to the body in 'pre-sleep'. However, in describing what sleep is we must also address what happens *during* sleep, that is the *architecture* of sleep.

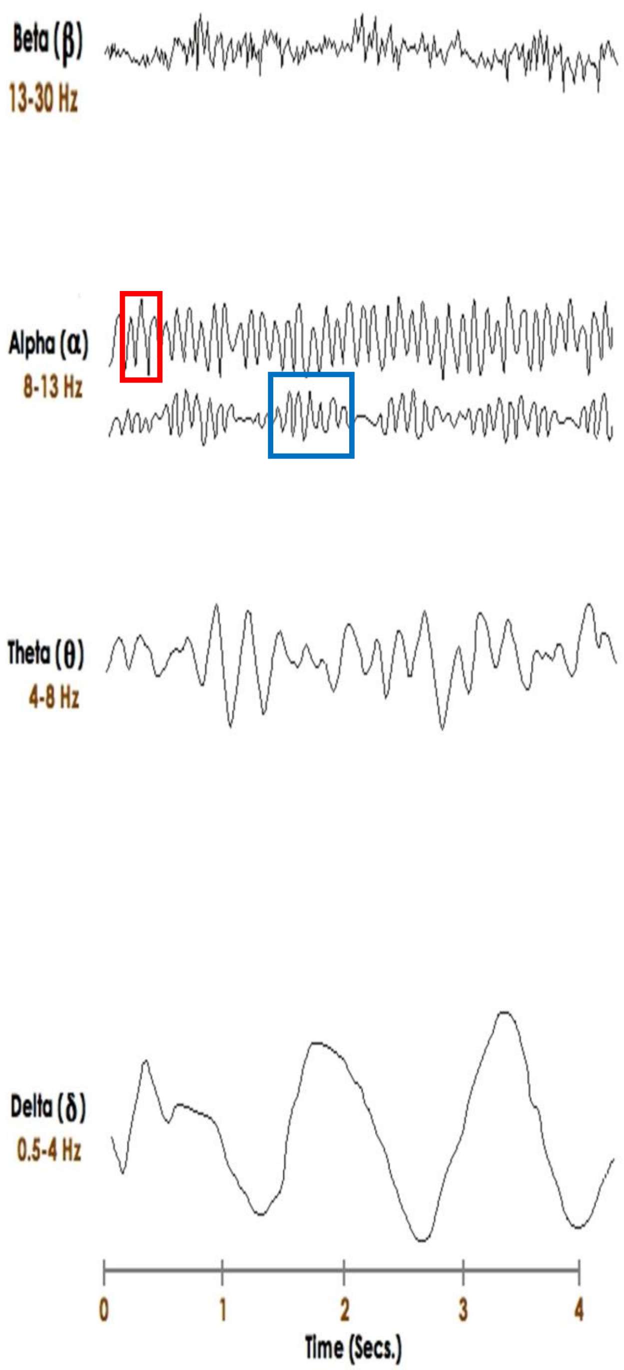
In contemporary sleep research, there are four stages of sleep, each with its own description and recognisable electrical brain wave patterns (electroencephalogram (EEG)) (Table 3.1). The scoring criteria for classification of sleep stages has changed and a previous five-fold system (Rechtschaffen & Kales 1968) was replaced in 2004 by the America Academy of Sleep Medicine with a four-stage classification system (Moser *et al.*, 2008, Gupta *et al.*, 2016).

Typically, a sleep cycle lasts 90 minutes and encompasses all four stages of sleep. The first three stages involve non-rapid eye movement (NREM) stages and make up the largest part of the sleep cycle (NREM 1, NREM 2 and NREM 3). As illustrated in Table 3.1, EEG traces during these stages involve rapid changes in architecture; Stage 2 displaying characteristic 'Theta' waves and Stage 3 displaying characteristic 'K complexes' and 'Sleep Spindles' as deeper sleep ensues. The final stage (4), involves rapid eye movement (REM) and has more frequent happenings later in the sleep period (Takahashi *et al.*, 1968). This is a deep stage of sleep, also referred to as slow wave sleep (SWS), (illustrated in Table 3.1), with intense activity in certain parts of the brain. Longer periods of slow wave sleep occur in the first part of the night, primarily in the first two sleep cycles. It is during REM slow wave sleep that memory consolidation and cognitive recovery aspects are thought to occur (Silva *et al.*, 2012).

Most healthy adults will have 4-6 sleep cycles per night. This equates to the recommended 6-8 hours of sleep per night which is the suggested amount to reduce morbidity and mortality risks. However, the individual nature of this is becoming more pronounced (Chennaoui *et al.*, 2014) with reports of poor sleep quotas reaching epidemic proportions and a call for Governments to lead on poor sleep as a major health risk (Johnston, 2017).

Table 3.1 The four stages of sleep and associated EEG trace (adapted from http://evolutionarypsychiatry.blogspot.com/2011/01/sleep-architecture.html)

Stage	Description	EEG Trace Example
Stage 1 (NREM1)	Transition to sleep Non-rapid eye movement sleep (NREM) Slow rolling eye movements Partial relaxation of voluntary muscles Relatively brief sleep stage (lasting up to seven minutes).	
Stage 2 (NREM2)	Non-rapid eye movement sleep (NREM) Shows characteristic patterns on the EEG including ‘K complexes’ (red box), a high amplitude wave (tall and wide) and ‘sleep spindles’ (blue box), closely spaced high frequency waves (not as tall and occur quickly over a short period of time) Need to be identified by trained individuals to identify sleep stages The stage you’d ideally wake in after a ‘nap’	
Stage 3 (NREM3)	Non-rapid eye movement sleep (NREM) The start of deep sleep Shows high amplitude activity (tall and wide EEG waves) known as Delta waves Reported as the deepest of the three NREM stages of sleep No eye movement or muscle activity. Difficult to wake up in this stage of sleep The brain produces even more delta waves and you move into an even deeper, more restorative stage of sleep next.	
Stage 4 (REM)	Rapid eye movement sleep (REM) Presence of rapid eye movement (REM) (the movement of your eyes in different directions while you are asleep) Is the smallest portion of the sleep cycle and occurs several times during sleep. The average adult has 5-6 REM cycles per night. A deep stage of sleep with intense activity in certain parts of the brain. This is the phase when most dreaming occurs, heart rate and blood pressure increase, and breathing becomes fast, irregular, and shallow. Slow wave sleep patterns present	



The architecture of sleep used to quantify, assess and illustrate sleep stages can be assessed through polysomnography (PSG). The sleep studies involved in this thesis do not involve PSG analysis, and specific methodologies employed with the various Sports' projects are provided in Chapter 5, however it is provided here as an explanation of the gold standard laboratory analysis of the architecture of sleep and quality.

PSG is used primarily for assessing clinical sleep disorders, although it can be expensive and limited in its ability to measure large numbers due to being labour intensive and requiring specific skills in electrode placement and analysis of outputs. Specifically, it can record body functions such as brain activity (electroencephalogram), eye movements (electroculogram), muscle activity (electromyogram), and cardiac activity (electrocardiogram) (Halson 2014). Information on sleep that can be obtained from PSG analysis includes, but is not limited to, total sleep time (TST), sleep-onset latency (SL), wake after sleep onset (WASO), sleep efficiency (SE), sleep fragmentation index (FI), number of awakenings, time in each sleep stage, and sleep stage percentages (Halson, 2014). To graphically represent the stages of sleep as a function of time, a form of PSG called a 'hypnogram' is used (Figure 3.1) which is a simplified version of a PSG output and was developed as an easy way to illustrate the recordings of the brain wave activity during sleep. Light sleep is depicted in stages 1-3 with more frequent light sleep episodes as the night progresses. This is when the circadian rhythm drive to sleep is decreased (sleep pressure falls), in the sense that physiological drivers for sleep diminish, e.g. melatonin levels fall. Deep sleep and REM sleep are also present throughout the night but more deep sleep is seen in the former stages of the nights' sleep when the homeostatic drive for sleep is more urgent.

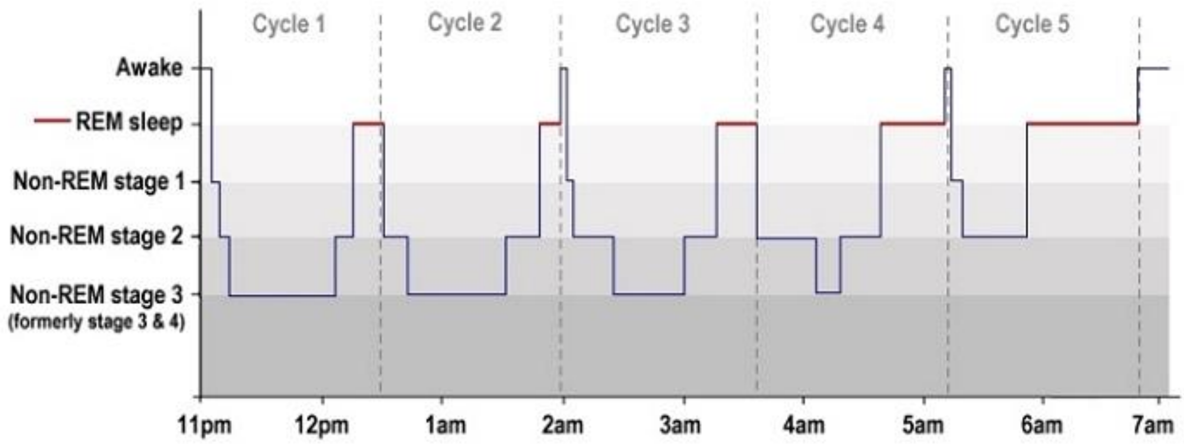


Figure 3.1 A normal hypnogram from a healthy adult (http://www.howsleepworks.com))
A simplified version of a PSG output, the blue line represents the different stages of sleep, exemplifying how sleep changes through the night. The red line represents REM (SWS) sleep.

3.5 Movement behaviour

Having described sleep; what it is, the proposed function of it, and its architecture, I shall turn to focus on 'movement behaviour' as this has formed an important secondary aspect of the fatigue management concept and in the analysis of the athletic populations I have observed.

Complementary to their sleep, consideration should also be given to athletes' rest or 'downtime' between training sessions and the cumulative affect over time i.e. days, week, training block, season, or Olympic cycle. This can be quantified through movement behaviour measurement and analysis, which essentially describes what you are doing when you are not sleeping. Therefore, either on their own gives only part of the picture, but sleep and movement behaviour combined provide a complete picture of an athlete's fatigue management over an entire day. Gaining information on both factors over a training phase, i.e. a microcycle, mesocycle or macrocycle, can be very impactful to an athlete's recovery education.

Whilst specific analysis of the frequency, intensity and duration of exercise has been reported in paediatric literature through activity counts (Trost, 2007), the capture and analysis of the daytime activity volume or 'movement behaviour' in elite athletes has not been widely reported. However, what has been reported is training load. Yet this remains exclusive to training sessions and is a limited analysis of only one part of an athlete's day (Halson et al, 2014, Drew & Finch, 2016).

Recently there has been some attempt to categorise athlete 'sedentary' behaviour through analysis of energy expenditure (Weiler *et al.*, 2015, Sperlich *et al.,* 2017). However, there were limitations to these studies in relation to the methodological assessment of sedentary behaviour and athlete 'eliteness'. For example, concerns over the validity of equipment used to measure physical activity (Weiler *et al.,* 2015) against gold standard measures (i.e. doubly labelled water, Aadahl & Jorgensen, 2003) and a lack of presentation as to what constitutes different levels of athletic training in terms of traditional measures of energy expenditure (e.g. Metabolic Equivalent of Task (METS)).

Despite extensive searching and discussions with colleagues, both in high performance sport and wider academic domains, regarding the quantification of movement behaviour, (exhibited through Actigraphy as daytime rest-activity profiles or 'activity counts'), no studies have used such data with an elite athlete population. Therefore, it appears that information is currently limited on the quantification of the movement behaviour, (exhibited through Actigraphy as daytime rest-activity profiles), of high performance athletes. Further, some authors have neglected providing specific descriptions of what they termed 'elite athlete' and lacked clarity in determining sedentary behaviour of the athletes' in relation to the level of overall training load completed. One study claiming athletes were at a health risk because of alarming sedentary behaviours but failing to recognise this behaviour was in relation to a full training programme for professional athletes (Sperlich *et al.*, 2017).

It is important to note the aim of the data capture process for rest-activity profiles is not to assess the *intensity* of activity or rest but the objective assessment of the *balance* between rest and recovery during waking hours over a 24-hour period. That is, the percentage of the amount of time an athlete spends being mobile or immobile during waking hours. To illustrate this, Figure 3.2 provides an example of a 24-hour Actogram and rest-activity profile (activity volume) over a one-week period in an elite athlete. Peaks and troughs can be identified for active and less active periods. Blocks of nocturnal sleep are identified with the shaded blue areas. This is determined from wearing an actiwatch and a detailed methodology for using such equipment is provided in Chapter 5.

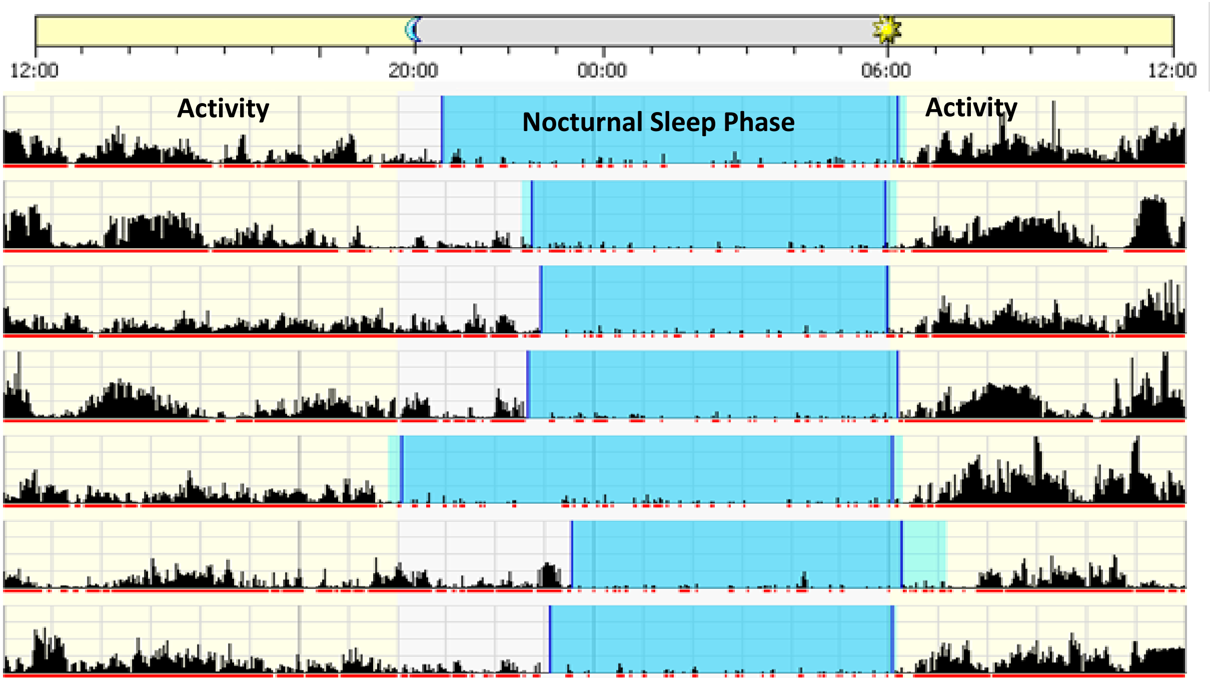


Figure 3.2 An actogram of an elite athlete
The blue area indicates nocturnal sleep and the black areas indicate activity volume. The Actogram is set for a 24-hr period midday to midday. Activity volume scale was set at 3000 for all athletes analysed (arbitrary unit).

Given the same field-based tools (i.e. an Actiwatch) used to measure nocturnal sleep characteristics and quality can also provide information on movement behaviour through direct assessment of activity volume and pattern assessment, both minimises the cost and participant burden (Lambiase *et al.*, 2014). This also allowed me to gather large amounts of data in this area for numerous sports.

3.6 Summary

I have presented a technical description of sleep to demonstrate what sleep proposes to be and how in its normalcy it is achieved through psych-physiological process. I have described the architecture of sleep and introduced its gold standard measurement tool (PSG – refer to Chapter 5 for methodology), and why, as a secondary analysis to sleep, movement behaviour can potentially add value to a practitioners' knowledge base about an athlete's ability to manage fatigue. The following Chapter will firstly examine how Sports Science literature describes sleep and athletic performance, and secondly discuss which scientific discipline 'owns' the study of sleep in a high performance context; and finally assess why we as practitioners should consider fatigue management (the monitoring of sleep and movement behaviour) in our practices supporting elite athletes.

Chapter 4. Sports Science Literature and Sleep

4.1 The sleep and athletic performance relationship

Historically, whilst high performance sport practitioners, coaches, athletes and academic research groups recognise sleep as a critical biological function, rarely has there been a focus on capturing data to inform athletes about their sleep (and associated movement behaviour). Consequently, the high-performance athlete's ability to manage sleep has seldom been examined/studied. This seems alarming given sleep and athletic performance have a reciprocal relationship; sleep affecting performance and performance affecting sleep (illustrated in Figure 4.1) (Chennaoui, 2015). Yet whilst there seems to be a reciprocal relationship between sleep and athletic performance and the timing of sleep in relation to athletic performance may have a positive or negative affect (Postulouche, 2005; Lastella, *et al.*, 2010), there remains the dilemma that no studies to date have investigated the effect in either direction from a truly mechanistic standpoint. Nor has it been fully investigated in the high-performance sport arena (Morgan, 2016). As such limited data exists which is partly due to the vast array of physiological differences, training and competition stressors (Fullager, 2015).

Consequently, the robustness of, and possible mechanisms, mediating the effects of sleep remain unknown and the relationship between sleep and athletic performance remains equivocal. Further research and attention are required to obtain a greater knowledge of the interaction between these two variables (Fullagar, 2015). I shall elaborate on this interaction in this chapter when I focus on some of the sports science literature and sleep.

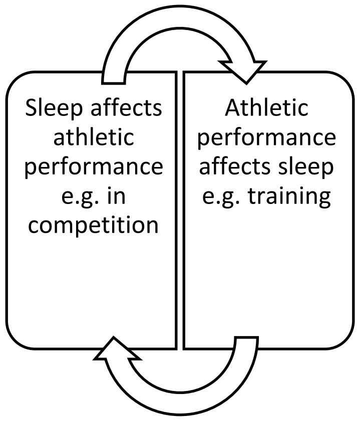


Figure 4.1 Schematic of the reciprocal relationship between sleep and athletic performance

As stated in Chapter 1, the principle aim of this thesis was to provide information as to how and why fatigue management, through assessment of sleep and associated movement behaviour, was introduced and evolved as a concept to the UK high-performance sport industry. Part of this process involved firstly identifying why I, as a physiology practitioner, felt compelled to lead the way in the initial data capture, measurement and assessment of fatigue management. Given the pilot work I was conducting within my work programme, outlined subsequently in Chapter 6, and the technical process of sleep, outlined in Chapter 3, I felt instinctively that as a physiologist, I should drive the process of fatigue management in the sports I was working with and take the lead in disseminating knowledge and information to the wider UK high performance sport industry. My process for the dissemination and knowledge transfer is described specifically in Chapter 6.

This chapter will provide discussion on the translation of sleep theory to applied practice in the high-performance sport arena and who 'owns' that process. I will include a detailed explanation as to why capturing, assessing and characterising sleep and movement behaviour for the enhancement of athletic performance is critical in contemporary sport science, and how its assessment and description will impact on science and medical service provision to elite athletes and their coaches. This comes with the caveat that sleep and movement behaviour interventions are a multidisciplinary process once data has been collected and possible solutions identified. For example, as the physiologist I may project manage a process to improve sleep quality, but the detailed intervention may be delivered by a practitioner in another discipline e.g. sport psychology. This process is highlighted in Chapter 6 through the example of the EIS decision tree for sleep assessment in athletes.

Secondly, evolving the concept of fatigue management involved highlighting key Sports Science research in relation to sleep and athletic performance. This will be elaborated on further on in this chapter where a general overview of some of the Sports Science sleep literature will be provided. I will focus on a broad background of sleep and athletic performance including an outline of the contemporary Sports Science sleep research, followed by the salient work that is required for an applied physiology practitioner to deliver their role. Sufficient evidence will be provided for a balanced perspective of the current technical findings in the sleep and athletic performance literature. For the purpose of clarity, I will focus on the studies that have been conducted up until 2017.

As a counterpoint, arguments against analysing sleep will be presented. Such as, the 'so what?', "why should we assess sleep"? and ''we all do it, so obviously need it, so where is the value in investigating individuals' sleep''? questions. Given sleep's diurnal pattern, some argue the need to investigate it is flawed given the (not so) obvious requirement for it. In the sporting arena these are questions coaches and support staff would frequently challenge me on and required carefully considered responses that, not only recognised their experiences in the elite sport domain, but also harnessed their drive to seek the next innovation that could provide a marginal gain.

Increasingly, it was becoming apparent that to achieve marginal victories over opponents, a culture of absolute preparation needs to be established. Therefore, it was no longer acceptable to be 'bravado' about how little sleep one claims to require to function normally, when the individuality of sleep can be objectively assessed and scrutinised for potential performance enhancement. This chapter will therefore outline areas where sleep (and associated movement behaviour) can potentially impact on training and performance.

4.2 Sport Science literature and sleep

Current anecdotal and some empirical evidence suggests sleep, and associated movement behaviour, deserve thorough analysis in the elite athletic population. Notably, Samuels (2008) reported the relationship of sleep to post-exercise recovery (PER) and athletic performance is a topic of great interest because of the growing body of scientific evidence confirming a link between critical sleep factors, cognitive processes, and metabolic function. However, it can be argued journal articles focusing on sleep and elite athletic populations remain sparse. Indeed, to date, little emphasis has been placed on the area of athlete sleep (and associated movement behaviour) and performance, both in the academic sphere and in an applied context. This could primarily be due to the complexity of sleep function, athlete availability and the individuality of sleep (Postolache, 2005 and Fullagar *et al.,* 2015).

Whilst in the general population it is postulated there is a relationship between exercise and sleep physiology via its impact on temperature, cardiac and autonomic function and the endocrine and immune systems and vice versa, what are not yet emphatically known are the mechanisms behind such interactions, both positive or negative (Chennaoui *et al.*, 2014). In addition, within the Sports Science literature, minimal reports exist for normative data regarding elite athletes sleep quality and characteristics (Leeder *et al.*, 2012, Gupta *et al.* 2016), with guidance provided by practitioners on what are determined as 'good' sleep strategies often being based on data from studies on the general population where the perception that 6-8 hours is the required amount of sleep (Chennaoui *et al*., 2014, Hirshkowitz *et al.*, 2015). However, this disregards any individual responses to sleep, gender, age, or specific sporting programme demands and relies on practitioner's ability to interpret what the science is telling us.

However, older studies have tended to focus more on sleep architecture (i.e. its electrophysiological make up) through the use of polysomnography (PSG) (refer to Chapter 5 for methodological detail), with recent studies becoming more ecologically valid by measuring and assessing sleep through subjective (e.g. Pittsburgh Sleep Quality Index, Buysse, *et al.* 1988) and objective field measures, as described in Chapter 5. For example, we know that anecdotal and limited empirical evidence indicates that athletes, as a group, experience degraded sleep quality relative to age-matched non-athlete controls (Leeder *et al.*, 2012), and that this sleep disruption is amplified during and immediately after competitions (Erlacher *et al.*, 2011).

Therefore, it can be said that the area is developing and the effect(s) of nocturnal sleep characteristics and quality on athletic performance, or vice versa, has advanced interest in the popular and academic literature over recent years. In fact, sleep and sport research was of interest in the 1980's but then went quiescent until the high-performance sport industry started to develop in the mid-nineties (as outlined in Chapter 1) (Morgan, 2016).

Undeniably, most research focusing on nocturnal sleep and athletic performance is concentrated in the 21st century (Silva A, *et al.*, 2012, Leeder *et al*., 2012, Sargent *et al.*, 2014a, Sargent *et al.*, 2014b & Fullager *et al.*, 2015). In this contemporary literature, what is often reported is that, in elite athletes, sleep and recovery between training bouts are paramount for optimising delivery of performance in training and competition given that being sleep poor can have significant effects on subjective measures e.g. motivation, perception of effort and cognition, as well as numerous other biological functions (Halson, 2008). Furthermore, nocturnal sleep and associated daytime recovery have often been reported as being important restorative process for high performance athletes to use in order to optimally recover and adapt for high volume training programmes. However, one should be cautious when the effects of sleep on athletic performance are typically labelled as impacting on 'recovery', with research outputs claiming 'loose' associations between sleep and successful recovery or restoration for sporting performance (Tuomilehto *et al.*, 2016). Remember, whilst some research has identified sleep as the 'gold standard' recovery strategy (Myllymaki *et al*., 2011; Samules, 2008), the exact mechanisms behind sleep, its restorative benefits and specifically if it is a physical or psychological benefit to overall athletic recovery, remains less clear. Yet sleep and recovery remain a global term.

Further, we need to be cautious over studies involving athletes and sleep as many studies have involved athletes 'in situ' and whilst this may enhance ecological and face validity, the studies can be criticised for being small in sample size and uncontrolled in terms of a comparative group and external variables e.g. diet and training load.

Most contemporary studies have focused on duration of sleep or objective measurements of sleep-wake patterns (e.g. total sleep time, sleep efficiency, and onset latency) through Actigraphy and self-reported measures (described in Chapter 5) (Halson, 2014, Gupta *et al.*, 2016). There has been less of a focus on sleep quality (the subjective experience and perceived adequacy of sleep) and the demands of athletic performance (Gupta *et al.*, 2016). Although, through the PhD I instigated (described in Chapter 6), we discovered that poor sleep quality and insomnia symptoms were high in elite athletes. Common mechanisms for this appeared to be pre-sleep arousal and sleep restriction. However, it must be noted that there were high levels of athlete variation and these findings could be related to any population under anxiety and stress (e.g. students during exam phase), not just athletic training or competition (Gupta, et al., 2016). We also discovered subjective estimates of sleep duration among athletes were generally inconsistent with objective measures (Gupta *et al.,* 2016). This is in line with Leeder *et al*. (2012) who reported subjectively, elite athletes display overall poorer signs of sleep quality when comparing athletes to an age and sex-matched control group. Our findings from the sleep PhD (described in Chapter 6) produced a comprehensive and systematic review of degraded sleep quality in elite athletes (Gupta *et al.*, 2016). Here, we provided reference tables of contemporary Sports Science literature and sleep relating to; characteristics of subjective sleep quality in athletes, subjective sleep assessment using the PSQI, prevalence of insomnia symptomology in competition and changes in athletic sleep patterns relating to travel and training. Our review has been one avenue where our pioneering work through the sleep PhD has informed current practices by ensuring practitioners are aware to consider both objective and subjective means of data collection when measuring the sleep quality and quantity of their elite athletes.

Of the contemporary Sports Science and sleep studies that have been published, rarely has the 'eliteness' of athletes been stated. This is an important point as elite athletes may respond differently to physiological or psychological assessment than sub or non-elite populations. For example, what is reported as a significant improvement in a sub or non-elite population in terms of their daily patterns of sleep and activity is likely to be different, as well as the impact on performance, in elite populations. Certainly, what measures as a significant improvement in performance in sub or non-elite populations, may not even register as a such in an elite population.

Indeed, Fullagher *et al.,* (2015) identified 205 studies specifically examining sleep or performance in relation to sleep loss and cognition in athletes, yet none stated the level of 'eliteness' of the athletes involved. Similarly, in our review (Gupta *et al.,* 2016), we identified that only a total of 37 studies (out of an original search result of >1600 articles) relating to sleep quality and athletic performance classed the athletes studied as truly elite. Therefore, studies directly involving 'elite' athletes, sleep and performance remain scarce. As a reminder, being truly 'elite' with regards to this thesis is in accordance with Swann's model for 'Classifying the Validity of Expert Samples in Sport' (CVESS) (Swann *et al.*, 2015), whose scale of 'eliteness' ranked participants on a continuum of categories from semi elite through to world class elite. In this model, athletes are assessed against set criteria relating to 1) within and 2) between-sport criteria. Within-sport comparisons are broken down to an evaluation of the participant's level of performance; the success achieved and the experience at that level; and between-sport comparisons include competitiveness of the participant's sport both on a national and global scale. Each individual component is ranked on a scale (score range 1-4, where 4 is elite) and computed. The outcome of this model is a quantifiable continuum of 'athlete eliteness': semi-elite; competitive elite; successful elite and world class elite (score range 1-16) (Gupta *et al.*, 2016). The athletes I have worked with in the examples provided in this thesis are classed as 'world class' in accordance with Swann's model.

Sleep is reported to play an important role in physiological and psychological recovery and, consequently, overall athlete health and well-being. Therefore, it seems pertinent that it has increasingly been explored and received more exposure in the Sports Science literature (Davenne, 2009, Halson, 2014, Gupta *et al.*, 2016), with most recent advances incorporating the effect on mental fatigue and performance in relation to the psychological decrements of being sleep poor (Banks & Dinges, 2007, Macora *et al*., 2009, Van Cutsem *et al.,* 2017).

Studies have taken different approaches to the effect of sleep disruption on athletic performance, some assessing physiological measures, some assessing specific athletic performances which are arguably more relevant (Thun *et al.,* 2015). Certainly, it has been recognised that athletes value their sleep for both health and performance reasons (Tuomilehto *et al.*, 2016). Fallon (2006) reported that a group of elite athletes ranked sleep characteristics as the most important clinical history variable in relation to short term fatigue and ranked sleep problems as the highest in terms of perceptions of the causes of short term fatigue. Venter *et al.* (2010) reported that 67 % of a cohort of athletes who were asked to rate recovery strategies used during the competitive phase of the year, reported a regular sleep routine. Environmental factors such as light and noise affected their sleep, with 41 %

indicating that they experienced problems falling asleep at night. Similarly, in a study conducted with my PhD student, we surmised that elite sport is associated with high levels of sleep disturbance, with differences being observed between sport-types (Gupta *et al.*, 2016). In this study we used the Pittsburgh Sleep Quality Index (PSQI), a reliable and valid self-report questionnaire (more details in Chapter 5), to measure over 400 elite British athletes. We reported that 15 % of the athletes measured stated their sleep had deteriorated since reaching an elite level of performance. Conversely, a large proportion (62 %) of the athletes assessed stated their sleep had remained unchanged since they had reached an elite level, suggesting that good sleep quality may not necessarily be a prerequisite for participating in elite sport, nor does it necessarily degrade it (Gupta *et al.* 2016).

Nonetheless, emerging (but un-replicated) evidence suggests that improved sleep quality can enhance individual (Mah *et al.*, 2011; Skein *et al.*, 2011) and team (Zhao *et al.*, 2012) athletic performance in both individual and team sports. For example, Zhao *et al.* (2012) reported a correlation between basketball players' sleep quality and distance in a 12-minute run test, whilst Mah *et al.* (2011) successfully implemented a sleep extension program in a group of collegiate basketball players. Here they instructed them to maintain a regular sleep–wake schedule (including daytime naps) and to aim for at least 10 hours in bed per night. They reported an increased sleep duration which was associated with significant improvements in sports specific performance as well as improvements in reaction time, daytime sleepiness and mood (Sergeant *et al.*, 2014a). Limitations to this study were that this group of athletes were non-elite and the actual strategies used to increase athlete sleep duration were not described. As stated previously, studies relating to specific elite performance benefits and the individual nature of sleep remain scarce.

Concerns over poor sleep quotas in the athletic population stem from the knowledge that despite individual requirements for sleep displaying large variations, a chronic reduction in sleep (e.g. less than 6 hours per day) can lead to a substantial disturbance in cognitive capacity (Boonstra *et al.,* 2007, Sergeant *et al.* 2014b). Reilly and Edwards (2007) conducted a meta analyses and reported generically, there is a significant impact of chronic sleep loss on psychomotor performance (e.g. reaction time). The longer sleep is deprived for the greater the effect on performance. Further evidence of this came from my own professional experience where I have observed several elite rowers who experienced becoming parents for the first time and suffered the concomitant sleep loss a new baby brings. Unfortunately, this led to decreases in performance in training and subsequent illness. Consequently, some hard choices had to be made by these particular rowers in terms of how they supported their family circumstances, particularly with a young baby's nocturnal awakenings during the night, whilst also needing to consistently deliver a training programme. Essentially, the rowers learnt to prioritise their sleep and came to an agreement at home regarding nocturnal support of babies and partners!

Throughout the literature, associations have been found between poor sleep and psychological factors such as motivation to train (Mah *et al*., 2011, Abeln *et al*., 2013) and cognitive function including mood state, concentration and decision making (Leger, 2008, Fullagar *et al.*, 2015) along with psychomotor performance and daytime sleepiness (Reilly & Edwards, 2007, Leger, 2008, Fullagar *et al*., 2015). Further, mood state measures are shown to be more sensitive than cognitive tasks and in turn cognitive tasks more sensitive than motor tasks to sleep loss (Pilcher & Huffcutt, 1996). Given athletic performance requires excellent skills in physical and psychological abilities, impairments in either area will likely impact on performance outcomes. Mood will also contribute in the sense that a detriment to mood state will affect an athlete's ability to maximise their determination and effort (Reilly and Edwards 2007, Macora *et al.,* 2009).

More acute sleep loss may still have an effect on performance, albeit less severe. In a study of swimmers, Sinnerton and Reilly (1992) reported after partial sleep deprivation (2.5 hour per night for four nights), swimmers had no decrements in physical measures but presented with a decreased mood state and vigour with a concomitant increase in depression, tension, confusion, fatigue and anger. Similarly, Reilly and Deykin (1983) reported decreases in psychomotor function but no effect on gross motor function tests in a group of trained men with three nights of sleep loss and one recovery night of sleep. The negative effects being notable after only one night of sleep deprivation. Interestingly they reported a beneficial arousal effect of exercise following sleep loss. This lends to the argument that a single night of sleep loss may not be so adverse to performance outcomes and could potentially be overcome through sleep extension techniques, nutrition and the sporting activity itself.

Nonetheless poor sleep has a multifactorial impact on athletes' ability to deliver quality training sessions and this is also shown through its impact on physiological function such as immune response, e.g. symptom expression may be higher (Konig *et al.*, 2002, Irwin, 2002, Cohen *et al.* 2009, Besedovsky, 2012, Hausswirth *et al.*, 2014,) and reduced parasympathetic activity expressed through higher frequency heart rate variability (Myllymäki, 2006, Spiegelhalder, *et al.*, 2011). Poor sleep also affects propensity for injury with, for example, athletes experiencing less than 8 hours sleep per night being 1.7 times more likely to experience an injury compared with athletes who slept for more than 8 hours (Milewski *et al*.

2014). Being sleep poor can also affect maintenance of body mass as a higher body mass index has been reported in individuals with a tendency for shorter sleep (Gonnissen *et al.*, 2013, Moraes *et al*., 2013), although this was in the general population.

As a general guide, Reilly and Edwards (2007) reported a taxonomy of sports and recreational activities affected by sleep loss and this is presented in Table 4.1. The caveat being this classification is highly generalised, limited to non-elite populations, and the effects of sleep loss are moderated by individual's perception of the level of challenge of the activity.

Additionally, the extent of the impact of poor sleep on athletic sporting performance is determined by individual athletes' *requirement* for sleep and their *responses* to poor sleep. Both of which are highly individualised and vary with gender, age, chronotype (more details later) and general level of health.

Table 4.1 A taxonomy of sports and recreational activities affected by sleep loss (Reilly and Edwards, 2007)

Characteristics	Sports	Effects
Low-aerobic, high vigilance	Sailing Road cycling Aiming sports	Errors ↑
Moderate aerobic, high concentration	Field sports Team games Court games	Decision-making ↓
High aerobic, gross skills	Running 3000 m Swimming 400 m	Marginal
Mixed aerobic – anaerobic	Combat sports Swimming Middle distance running	Power ↓
Anaerobic	Sprints Power events	Marginal
Multiple anaerobic efforts	Jumping events Weight-training	Fatigue ↑

Whilst successful sporting performance is a result of a myriad of factors, how an athlete manages their sleep and responds if they experience poor sleep, suggests there is an element of natural selection, in terms of who can cope with poor sleep, occurring within the athletic population. A tool to help measure this is the Ford Insomnia Response to Stress (FIRST) questionnaire. More details of this are provided in Chapter 6, but briefly, this is a subjective questionnaire specifically designed to identify 'reactive sleepers' i.e. those who are sensitive to interventions to improve sleep quality. It therefore provides practitioners, coaches and athletes with an awareness of those individuals who are more likely to be sensitive to sleep disturbances. Importantly, this doesn't discriminate elite athletes as the sole population experiencing sleep reactivity. The propensity for sleep reactivity can manifest in any number of scenarios, for example ballet dancers prior to a premier or university students during exam periods (Fietze *et al.*, 2009, Ahrberg *et al.*, 2012, Gupta *et al.*, 2016). However, if an individual with high sleep reactivity finds themselves in an elite sporting environment, then potentially they may be at a greater risk than other athletes of degraded sleep quality when placed under certain circumstances e.g. selection/competition stress.

From contemporary Sports Science literature, one can generally conclude that elite athletes experience high levels of sleep disturbance, characterised by symptoms of longer sleep latencies, greater sleep fragmentation, non-restorative sleep and excessive daytime fatigue (Gupta *et al.* 2016). One must be cautious that this is limited to athletic populations, as similar statements can be argued for other populations as the aforementioned ballet dancers or students. Nevertheless, three areas have generally been identified as precipitating factors to be associated with athletic performance and sleep disturbance/reduced sleep quality and have most recently been reinforced through our systematic review (Gupta *et al.* 2016); 1) training, 2) travel (Winget, 1984, Bishop, 2004, Waterhouse *et al.*, 2004, Waterhouse *et al.*, 2007 & Forbes-Robertson, 2012) and 3) competition (Juliff *et al.*, 2014), Kolling *et al.*, 2016). For the purposes of this thesis I have added in a fourth area; chronotype. I shall now elaborate on these areas.

4.2.1 Precipitating factors: training

Sleep quality and structure among elite athletes is challenged by the physiological stress of training and competing (Shapiro, 1981, Taylor *et al.*, 1997, Hausswirth *et al.*, 2014), the emotional stress of competing (Taylor *et al.*, 1997, Erlacher *et al.*, 2011, Juliff *et al.*, 2014), and the circadian demands of integrating training programmes into school, university and family life. Training is clearly imperative to successful sporting performance and the reciprocal relationship of sleep and athletic performance is no better exemplified than through this critical determinant of performance. For example, sleep can be disturbed in elite athletes in response to training loads and in some cases, the consequences of inadequate sleep can result in reduced training through either overtraining or maladaptation (Taylor, 1997, Wall *et al.*, 2003, Meeusen *et al.*, 2006, Main *et al.*, 2010, Smith *et al.*, 2011, Brink *et al.*, 2012, Hausswirth *et al.* 2014).

Further, training routines of certain sports may negatively affect an athlete through the constant sleep debt experienced in having to schedule get up times very early in the morning. Swimming and rowing are sports who traditionally demand athletes commence training before 0800 on a daily basis, which necessitates a get up time of typically 0600 (SD 0.04) (Gilchrist, 2016). Early morning training affects sleep through restriction of it and this can be detrimental to psychomotor performance and reaction time (Sargent *et al.*, 2014a). Unless athletes are conscientious enough to get to bed early to ensure sufficient sleep, this can potentially have a negative effect on training and ultimately performance. Whilst it is highly individualised, a sleep debt of less than 6 hours a night is typically reported as having a detrimental affect (Sargent *et al*. 2014). The consequent sleep debt associated with chronic sleep loss can then impact on an athlete's ability to deliver consistent training either in a single episode, or more significantly, over meso and macrocyles and therefore ultimately impact on competition performance, whether it be in one season or over an entire Olympiad.

Using markers to indicate training having a negative effect of performance, Hausswirth *et al.* (2014), found indicators of sleep disturbance in triathletes, who underwent an overload training period, returned to baseline in a subsequent recovery period. Similarly, Kolling *et al.* (2016) found disturbed sleep in elite junior rowers during an intense training period and Shaal *et al.* (2015) found decreases in actual sleep duration and sleep efficiency with increased sleep latency and fatigue compared to baseline after 2 weeks of intensified training in synchronised swimmers. Taylor *et al.* (1997) investigated training volume influence on slow wave sleep and psychological stress and reported a reduction in slow wave sleep (nREM sleep) during the taper, indicating a link with slow wave sleep and exercise duration and intensity. The above studies indicate that the effect of training load on sleep is a matter for consideration by coaches and support staff and adds justification to the argument that practitioners should feel compelled to capture data on baseline athletic sleep and monitor at relevant opportunities within the Olympic/Paralympic cycle.

Included in a discussion of the effects on training and sleep (or vice versa) are the concepts of training camps and environments. From some studies of elite team sport players on training camps, observations have been made between changes in training load and different sleep environments on total sleep time (TST) (Pitchford *et al.*, 2016, Thornton *et al.* 2016. Remaining at home and training in a familiar environment compared to travelling away from home where an athlete is potentially sharing a room in a foreign environment, may affect their sleep both short and long term. Pitchford *et al.* (2016) reported, in elite Australian Rules football players, an increase in session rating of perceived exertion (sRPE) during a training camp and compromised sleep quality, through an increased time in bed, (+34 minutes) in the absence of increased total sleep time. This consequently significantly reduced training camp sleep efficiency (-5.82%) and was despite external influences to sleep changing i.e. time zone shift or training schedules. This could, in part, be explained through Macora, *et al's.,* (2009)'s investigations of mental fatigue prior to exercise, where the investigators found that mental fatigue limits exercise tolerance in humans through higher perception of effort rather than cardiorespiratory and musculoenergetic mechanisms (Macora *et al*., 2009).

Conversely, my personal observations on elite rowers have shown that they experience no significant differences in the sleep variables of time to bed (hh:mm), time in bed (min), get up time (hh:mm), actual sleep time (min), sleep efficiency and sleep latency (min) when comparing UK versus training camp environments. This is predominantly due to the regimented training regime in the sport of rowing. However, good sleep hygiene practices (which is all environmental and behavioural aspects which precede sleep) were reinforced through my work with the rowers and are detailed later in this thesis (refer to Chapter 6 and appendix 4).

Another factor to the scheduling of training is whether an athlete has a certain chronotype[6]. That is the assessment of an athlete to establish if they are a morning, evening or intermediate type of person (Postulouche, 2005; Lastella, *et al.*, 2010). A person's chronotype is a basically a genetically predetermined predisposition which modifies an individual's preference to be most active in the morning, middle of the day or evening (Lastella, *et al.*, 2010). Although, the exact causes and regulation of chronotypes e.g. flexible versus fixed chronotypes and developmental changes are uncertain. Potentially an athlete's chronotype could influence training and competition performances along with the natural selection of an ability to 'cope' when choosing a particular sport to potentially excel in. For example, an athlete with a propensity to be more alert in the morning may achieve better training in sports where traditionally early morning training is the norm (e.g. swimming, sprint kayak and rowing) and may overcome the associated negative effects on sleep of early morning training.

[6] Chronotype is a behavioral manifestation of underlying circadian rhythms of the plethora of physical processes. A person's chronotype is the propensity for the individual to sleep at a particular time during a 24 hour period. For example, 'eveningness' (delayed sleep period) and 'morningness' (advanced sleep period) are the two extremes with most individuals having some flexibility in the timing of their sleep period.

Certainly, timing of training schedules can potentially impact on the amount and quality of sleep obtained by elite athletes (Sargent *et al.*, 2014b) and if an athlete's chronotype is for being an 'evening type' then potentially this is a disadvantage in sports that begin training in the early morning. Early morning training sessions have their advantages, for some sports, in that they can provide good recovery time between training sessions, mimic competition schedules and allow time for technique to be worked on, particularly in favourable conditions e.g. water sports (Lastella *et al.*, 2010). However, there can be a detrimental effect of early morning training given the sleep loss athletes experience in order to get up early for training. From previous studies (Leeder *et al.* 2012, Sargent *et al.* (2014b) and personal findings through my work with elite athletes, we know athletes tend to experience an average of 6.5 hours of sleep per night. Further, those athletes in sports involving early morning training sessions experience a reduction in sleep duration and an increase in pre-training fatigue levels. For example, Sargent *et al.* (2014b) found, in a study of elite swimmers' early morning training regimes, that for sleep periods that preceded a training day, participants spent 7.7 hours in bed and obtained 5.4 hours of sleep (i.e. 71% of time in bed). For sleep periods that preceded a rest day, participants spent 9.3 hours in bed and obtained 7.1 hours of sleep (i.e. 77% of time in bed)''.

Certainly, in the rowers I have observed, a typical one hour reduction in sleep per night in a normal training phase, is not unusual (Gilchrist, 2016). Sargent *et al.* (2014b) also observed the cumulative effect of early morning training over only five days of training at 0500 hour and reported it led to a cumulative sleep debt of 8 hours 30 minutes. This is a potential issue given that to avoid detriments to daytime function an average of 8 hours per night is recommended; whilst there is no set amount of sleep reported for athletes, the common consensus is the same as for the general population (the American academy of Sleep Medicine and Sleep Research Society, 2015). This places athletes at risk particularly, for example, during periods of heavy training load or competition. Therefore, coaches should be aware of the implications of the timing of training sessions for sleep and fatigue when planning training programmes. As a strategic counter measure, in cases where early morning starts are unavoidable, sleep extension practices (e.g. napping) should be incorporated during the day (if athletes are amenable to sleep extension techniques), and optimal sleep hygiene practices (refer to Chapter 6 and Appendix 4) considered at night. This could potentially help negate the effects of restricted sleep on individual athlete performances for reasons already eluded too and also outlined further on in this chapter and in Chapter 6. This is important given previous studies in other populations with early morning start times e.g. airline crews, have reported that the general consensus is 30 minutes of sleep is lost for every hour that the start of work was advanced prior to 0900 hour (Spencer and Montgomery, 1997). For example, starting training ('work') at 0700 would result in a sleep loss of one hour. This doesn't sound too detrimental unless you need to be up early on a regular basis and accumulate an associated sleep debt. It is under these circumstances that a chronic sleep issue can ensue. Extrapolate the early get up times over a season or Olympiad and it is easy to see how sleep debt can accumulate.

Therefore, pre-training fatigue through sleep restriction can have implications both acutely and chronically in terms of the ability to deliver an optimal training session and to recover adequately for the next. This, coupled with the previously described negative effects of poor sleep, e.g. impaired immune function, means that elite athletes' performance may be suffering as a result. Even when athletes compensate and adopt sleep extension techniques, e.g. earlier time to bed or napping, this is often insufficient to compensate for the total sleep lost over a period of time such as a training block or a season (Sargent *et al.* 2014b).

The question arises as to whether those athletes successful in 'early morning sports', e.g. swimming, sprint kayak and rowing, are predisposed to be successful in their ability to tolerate early morning schedules or that they in fact 'entrain' to become able to cope with the early morning training demands. This is a difficult question for performance directors and coaches when planning training, particularly when this can sometimes be limited by access to facilities. It also has implications for performance pathway (talent identification) plans for sports. I would suggest that whilst an athletes chronotype can influence their 'wakefulness' at different times of the day and their ability to train optimally in a given sport, other factors also come into play when critiquing if an athlete is predisposed to a certain type of sport, for example, passion for the sport, financial position and locality to training venues. Further, lifestyle and physiological factors often mean it is difficult to have sleep onset much earlier in the evening before an early start for training. Insufficient evidence exists about athlete chronotypes, therefore given the area is under researched, more is required to take into account personality traits to better capture the sleep need of elite athletes (Gupta *et al*., 2016).

In terms of an athlete's desire for longevity in high performance sport, cumulative sleep debt can affect athletic performance and therefore good fatigue management strategies need addressing in such circumstances. Equally, a single night of sleep debt may affect training or performance in the short term but can be overcome, e.g. through correct nutrition, relaxation and sleep extension strategies. The concerning point here is that many athletes have limited methods for managing their sleep strategies to overcome the fatigue from a single night of sleep deprivation or longer (Juliff *et al.* 2014, Erlacher *et al.*, 2011). Therefore, they, their coaches and support personnel, would benefit from effective fatigue management strategies which take into account the specific demands of a sport's training schedule and an athlete's particular chronotype.

Coupled with a predisposition to be a 'morning', 'evening' or 'intermediate' type person, is one's 'sleep reactivity'. Similar to chronotype, this is genetically pre-determined and is a way of measuring how a person reacts to stressful situations through their sleep. It can be assessed through the Ford Insomnia Response to Stress Test questionnaire, a diagnostic self-assessment questionnaire using nine items which measure the propensity for disturbed sleep under stress and ultimately can aid in identifying individuals predisposed to insomnia (Drake *et al.*, 2008). The instrument tests the likelihood that an individual will get sleep disturbances following various stressful events; for example, in sport this could involve training load increases, selection phases or competition phase. In athletes this can be particularly prevalent as it can help predetermine times of poor sleep in an individual athletic career through identified poor sleep inducing occurrences.

4.2.2 Precipitating factors: travel

Travel is a regular disruption for elite athletes as international competition and training camps before major competition become more sophisticated (Pipe, 2011). One primary concern for travel and the associated fatigue is its effect on sleep. This includes an individual athlete's sleep architecture, hygiene and strategies.

My challenge as a Sports Science practitioner was to introduce sleep measurement and analysis to my assessment battery because I have to overcome previous misconceptions that sleep and athletic performance only become a performance issue when international travel is part of the agenda. Certainly crossing multiple time zones and the associated effects of such travel on circadian rhythm, and consequently sleep, can have a detrimental effect on the body's ability to deliver athletic performance, however the extent to which the affects manifest and the time frame of symptoms very much depend on the number of time zones crossed and the individual athlete's response to long haul flight associated jet lag (Waterhouse *et al.*, 2000, Waterhouse *et al.*, 2004, Pipe, 2011, Reilly *et al.*, 2007, Forbes-Robertson *et al.*, 2012 and Samuels, 2012). Nevertheless, it is not always the case that long haul travel (and associated jet lag) is the only travel category with negative connotations for athletic sleep. Both short haul and unadorned 'travel fatigue' can also have a detrimental effect.

Fundamentally, the difference between short and long haul travel symptomology are that the symptoms of jet lag are a function of *circadian desynchronization* and largely episodic, whereas the symptoms of travel fatigue are *cumulative* and *chronic* (Samuels, 2012). Therefore, the physical decrements of travelling fall into two categories; 1) the physiological stress of travel relating to circadian de-synchronisation (altered body clock) through flight times and 2) the 'travel fatigue' symptoms exhibited from short haul travel, e.g. the diurnal variation of physical attributes (i.e. whole-body flexibility; self-selected work rate, leg strength, some hormonal markers and core temperature), cognitive function and dehydration (Waterhouse *et al.*, 2004). To help identify the physical decrements of long haul (jet lag) and short haul travel, Samuels (2012) provides a comprehensive jet lag and travel fatigue management plan for Sports Medicine practitioners and high performance sport teams. Within this is a ‘Symptom Management’ algorithm (Figure 4.2), where the goal is to minimise jet lag symptoms by effectively addressing circadian resynchronisation, while monitoring the athlete for cumulative fatigue, managing the impact of travel, and preventing the health consequences associated with travel.

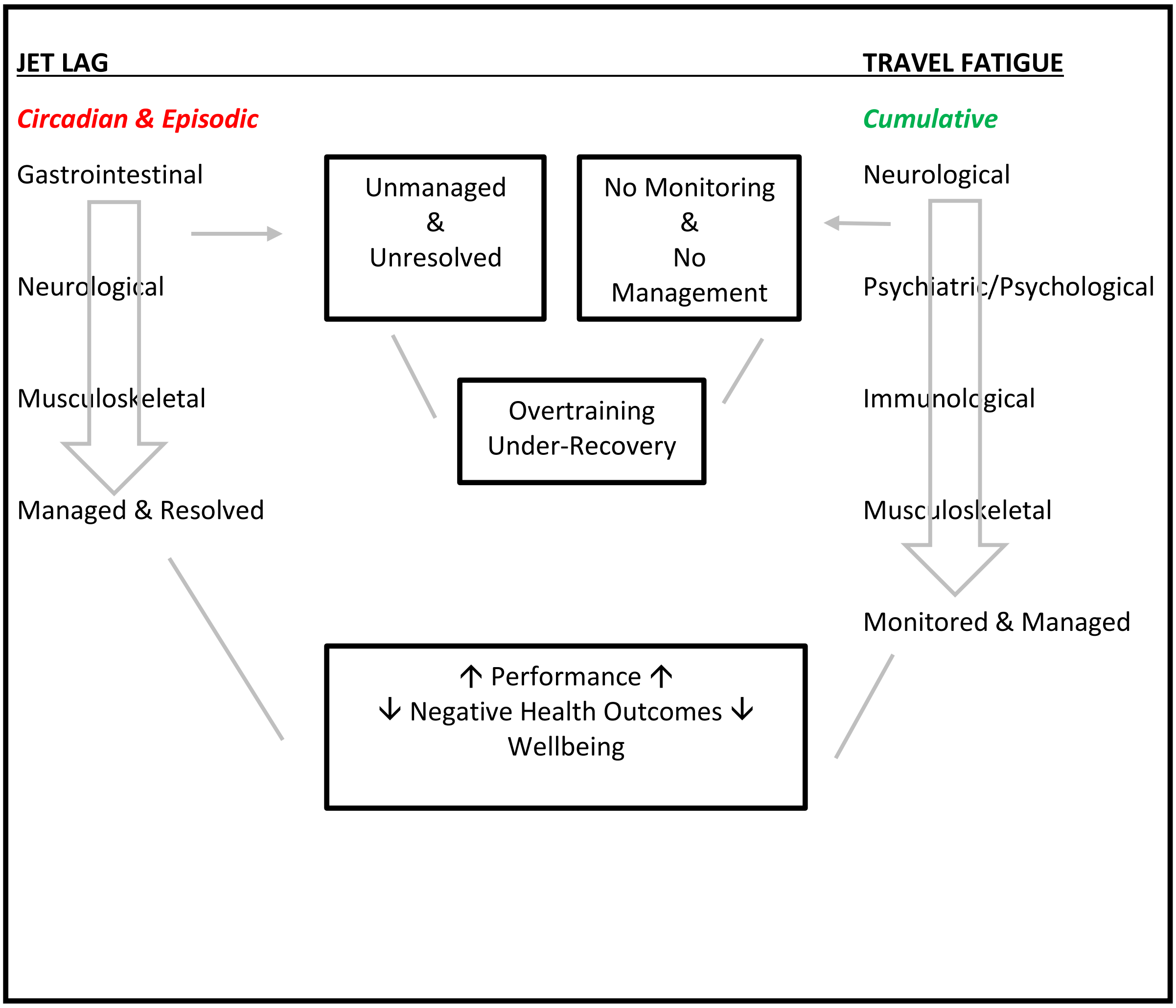


Figure 4.2 **Jet lag and travel fatigue symptoms and management algorithm (adapted from Samuels, 2012).**
Performance is enhanced and health and wellbeing maintained with a well-managed jet lag or travel fatigue programme.

Given the symptomology of travel and jet lag, an inadequate travel strategy can have detrimental effects on subsequent performance. Where sports prioritise training or competition schedules over travel schedules, sleep deprivation factors from travel fatigue can affect recovery, e.g. through exceptionally early flights. A converse approach, involving sensible travel schedules, could benefit performance by avoiding the short-term fatigue associated with travel to competition/training camps, combined with an optimal fatigue management strategy upon arrival at the destination. One must note however with long haul flights, crossing multiple time zones and resultant jet lag cannot be avoided. Here sports administrators, and coaches, can help to plan effective travel strategies to allow for time zone shifts and associated jet lag. They must bear in mind individual athlete's responses to jet lag and prioritise time to allow the symptoms of jet lag to abate in addition to phasing in training and/or competition post flight. Working backwards from the point of performance to the day of travel is a good strategy to follow in these circumstances. For example, Waterhouse et al (2002), in a study of 85 athletes, coaches and academics flying from the United Kingdom to Australia (two flights with a one hour stopover in Singapore), found the amount of sleep in the first flight was significantly greater in those who had left the United Kingdom in the evening than the morning (medians of 5.5 hours and 1.5 hours respectively; $p = 0.00$, Mann-Whitney). Whereas there was no significant difference on the second flight (2.5 hours *v* 2.8 hours; $p = 0.72$). They reported that increasing age and a later time of arrival in Australia were associated with less jet lag and fatigue, and previous experience of travel to Australia was associated with an earlier time of getting to sleep. Therefore, they concluded that there is a requirement to consider the importance of an appropriate choice of itinerary and lifestyle for reducing the negative effects of jet lag in athletes (and others), who wish to perform optimally in the new time zone.

4.2.3 Precipitating factors: competition

Whilst sleep can affect performance in athletes so, conversely, can performance affect sleep. Typically, this manifests in periods of competition. The demands of competition can play a part in the state of an athlete's sleep quality (Silva *et al.*, 2010, Erlacher *et al.*, 2011, Lastella *et al.* 2014, Chennaoui *et al.*, 2016, Kolling *et al.*, 2016) with internal factors reportedly being the main reason responsible (Juliff *et al.*, 2014). An investigation of the sleep/wake behaviour of endurance cyclists, before and during competition, found that compared to baseline, cyclists had less sleep the night before competition (6.5 ± 0.9 h) and during the first night of competition (6.8 ± 0.8 h) (Lastella *et al.*, 2014). Similarly, Erlacher (2011), reported of the 632 German athletes, from various sports, who were asked about their sleep habits during the night(s) before an important competition or game, 65.8% stated that they had slept worse than normal at least once on the night(s) before an important competition or game. Further, compared with male athletes, there was a tendency for more female athletes to report poor sleep before a competition (64.4% men vs. 67.9% women) and athletes from individual sports (69.3%) reported poor sleep more often than athletes from team sports (59.6%). In total, 62.3% of the athletes stated that they had slept more poorly than usual at least once on the night(s) before an important competition in the preceding 12 months. In a study of over 200 elite athletes, Juliff *et al.* (2014), reported that competition led to altered sleep disturbances through problems falling asleep, anxiety and nerves.

Conversely, Gupta *et al.* (2016) identified 6 studies using actigraphy to analyse sleep in competition and reported that most showed no significant changes in sleep efficiency and sleep onset latency when compared to normal training. Further, Chennaoui (2016) found that elite swimmers finishing fourth at national championships (France) had more consistent total sleep times for the duration of the competitions compared with those swimmers finishing fourth or below.

In order to aid coaches planning, the impact of in-competition recovery and, ultimately sporting performance, further research is required focusing on sleep quality during the specific stages of competition; pre, during and post. Furthermore, education of athletes on strategies to prevent poor sleep associated during competition phases is also warranted (Lastella *et al.*, 2014, Juliff *et al.*, 2015). Also, of importance is to recognise the difference between poor competition sleep and chronic sleep issues in athletes (Juliff *et al.*, 2015).

4.3 Should we measure sleep?

The high-performance athlete's ability to manage their sleep and rest (movement behaviour) has seldom been considered. This is because the assessment of an athletes' physiological, psychological, biomechanical and technical capabilities predominates training sessions. Adding measurement and analysis of sleep and movement behaviour to an already hectic assessment battery has often been considered too intrusive. This view is further reinforced when you consider the athlete's home environment as the single place they escape assessment and objectivity. However, minimising the intrusion with a simple device, such as an Actiwatch (refer to methodology in Chapter 5), allowed me to gain data in an area previously under-investigated.

In questioning 'should we measure sleep', I think it's important to state what it is I was actually measuring and consider if we, as practitioners, know what to do once we have data on sleep and movement behaviour. In terms of what was being measured, the sleep and activity variables measured by the actigraphy methodology are outlined in Chapter 5, with a corresponding description of sleep *quantity* (duration) and *quality* (described) (Galambos *et al.,* 2011). These two aspects of sleep are what I was considering when assessing the sleep side of an athlete's fatigue management.

Once we have data on athletes sleep quantity and quality it is important we have clear guidelines on how to act. My initial pilot work on sleep (described in Chapter 6) highlighted these guidelines did not exist. In Chapter 6, I provide procedures on how to provide support to athletes when conducting fatigue management projects through the described EIS 'Hierarchy of Needs (for the measurement and assessment of sleep and movement behaviour in elite sport)' and 'Sleep Management Decision Tree' (Figures 6.1 and 6.2 respectively). These two diagrams were established from my introduction of fatigue management to the UK high performance sport industry. What coincides with this is the non-negotiable aspect to any fatigue management assessment. By this I mean that the individual practitioner is aware of their professional boundaries and refers results of an athletes sleep assessment to appropriate members of the particular sport's Sports Science/Medicine team. For example, if an athlete is displaying signs of physiological insomnia, through objective and subjective measures, the athlete should be referred through their Sports' medical stream for clinical psychological help (e.g. Cognitive Behavioural Therapy (CBT)), to potentially help combat the insomnia.

When considering if we should measure sleep, the importance of capturing and analysing sleep for the benefit of athletic performance has, at a rudimentary level, been queried in terms of the fact that ''we all sleep and therefore why measure it?'' However, if you follow this train of thought then one could argue that we all breathe so therefore why measure aerobic capacity? Yet the assessment of one's aerobic capacity is a fundamental part of the physiological assessment of elite athletes as, primarily, it establishes individual characterisation of respiratory function and provides indicators of adaptations made and manipulations required for enhancement of performance. Therefore, whilst some argue against the need to measure objectively sleep quality and quantity, it is increasingly evident that, in elite sport, to achieve marginal victories over opponents, a culture of absolute preparation needs to be established. Further, whilst it is important to recognise academically the aforementioned reciprocal relationship between sleep and athletic performance, the ability to apply the theory in a practical context is of clear importance too.

In considering if we should measure sleep, we cannot ignore the association between sleep and athlete health as well as performance. Sleep is typically considered to be an aspect of 'athlete health'. That is an athlete's social, economic, psychological and medical wellbeing and how this translates to adherence to training and ultimately athletic performance (Chennaoui, 2016). As one interviewee stated,

> P5 ''Yes. It's not really realistic for us to say, "Oh, sport's bad for sleep". It might not have a, it might leave a legacy that is not especially helpful for me to life, but that is not the issue here. The issue here is performance and athlete wellbeing''.

Figure 4.3 displays how, along with associated factors, athlete health can contribute to sporting performance. It illustrates how being in the centre of a tiered pathway to sporting performance, there is a consequent rationale to focus on the characteristics of fatigue management (sleep and associated movement behaviour) in elite athletes and highlight areas for improvement.

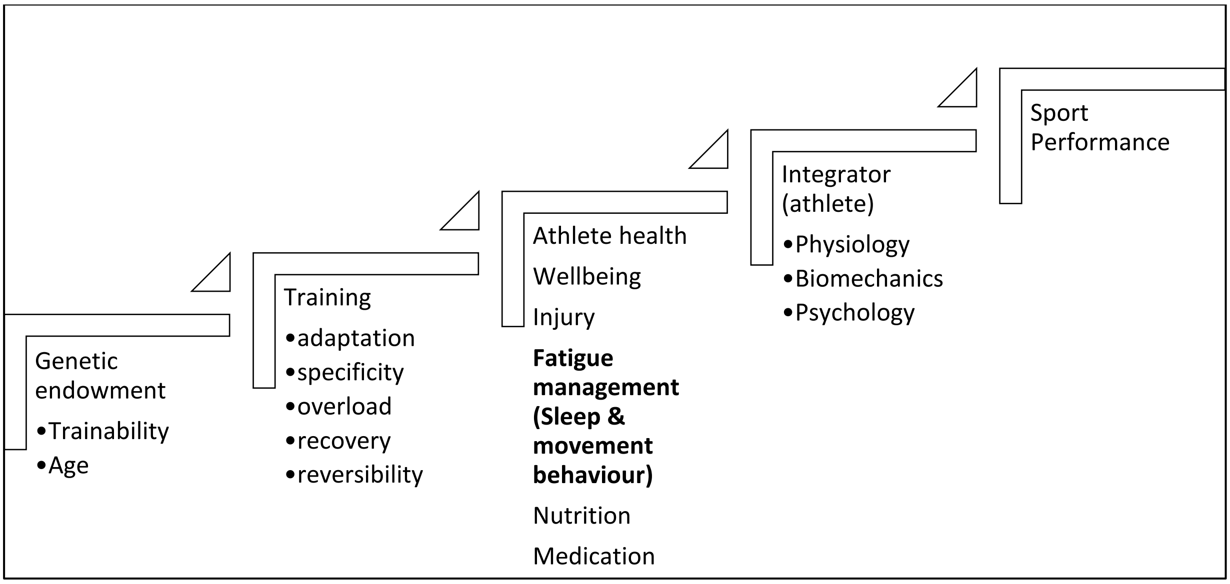


Figure 4.3 Schematic illustrating the factors associated with sport performance (adapted from Smith, 2003).

Of note, athlete health is a major objective of the UK high performance sport system and one of the key priorities of the EIS. The formation of a directorate within the EIS dedicated to matters relating to 'athlete health' in 2016, because collectively injury and illness is one of the single biggest factors that prevents athletes from being successful and sports from achieving medal targets, highlights the focus on such an area (English Institute of Sport, 2018). Primarily, the Athlete Health Directorate help sports monitor the availability, effort and recovery (AER) of their athletes in the context of their own individual narrative (English Institute of Sport, 2018). This includes a subjective assessment of athlete sleep. Additionally, within the EIS Athlete Health Directorate there is a dedicated working group focused on the management of upper respiratory tract infection (URTI) as athletes' self-report measures have concluded that URTI's contribute significantly as a cause for interrupted training regimes. I used my knowledge on sleep and its impact on the immune system to help this working group make recommendations to athletes on avoiding URTI's. Similarly, there are also projects within the Athlete Health Directorate dedicated to athlete's travel strategies including plans for sleep and short and long haul travel and performance and I have contributed, alongside my PhD student, to outputs for sports on sleep and travel strategies e.g. Team GB Rio 2016 Olympic Games travel strategy.

4.4 Technologies

Contemporary technologies for sleep assessment, e.g. smart phone applications, can be guilty of promoting sleep as a problem variable rather than as an area of human function needing to be individually described. Also, whilst such 'gadgets and gizmos' are a cheaper alternative to scientifically validated equipment (described in Chapter 5), they can be counterintuitive to good sleep. They have often 'piggy backed' on medical-grade methodologies and can be invalid against gold standard quality assurance measures (refer to Chapter 5). Nonetheless, manufacturers were happy to oblige and the consumer market for 'sleep wearables' has exploded (Byrne, 2017).

> "The trouble with sleep watches" is that the manufacturers generally do not make their hardware, algorithms or validation studies public (if they even did a study). So how do we know if they work? Many now purport to measure sleep stages (e.g. REM sleep) as well as sleep wake cycles. At best, actigraphs can infer sleep. Currently, only brain wave technology can measure sleep stages. Remember that sleep is in the brain and our brains are not on our wrists. Inferring sleep from wrist motion is complicated and requires independent validation against PSG regardless of the hardware or algorithms'' (Byrne, 2017).

Further, in the digital age in which we live, social media is littered with advice on how to achieve optimal sleep. However, guidelines are often based on population norms and have little consideration for individual variances. Therefore, technologies are frequently reported to help assess sleep but often they are absent from any form of quality assurance mechanisms for validity and reliability. Consequently, they fail to provide an accurate assessment of an individual's sleep characteristics and quality. This is a challenge for the practitioner where athletes can access information and technologies in the public domain easily, but with little comprehension of the importance of quality assurance practices used to assess sleep and the knowledge interpretation and dissemination surrounding the topic. In these instances, as a practitioner, it is important to reiterate to and help educate the athlete about validity and reliability of any equipment that is being used to provide the athlete (and coach) with information to assist in performance preparation. It is the athletes prerogative if they wish to engage with contemporary technologies such as 'wearables', however they should be at least in a position to make an informed decision about what they may or may not use. The physiologist should strive to be the one to provide the information to help the athlete make informed decisions.

4.5 Sleep Management Strategies

Having learnt about sleep in current sports science literature and some real world applications, I shall now present some suggestions for sleep management strategies based on current research and pragmatic approaches to improving sleep in athletic performance. The nature and effectiveness of sleep management strategies to maintain athletic performance following sleep disruption and circadian challenge remain either undeveloped, or untested (Morgan, 2013). It is therefore important that sleep and associated movement behaviour are captured for objective measurement and assessment in high performance athletes. Whilst studies pertaining to sleep quality in athletes have presented interesting findings relating to the generic aspects of sleep and athletic performance (Taylor *et al.*, 1997, Erlacher *et al.*, 2001, Hausswirth *et al.*, 2014 and Juliff *et al.*, 2015) and even hints towards normative data (Leeder *et al.*, 2012), there have been limited specific studies on interventions to improve athletes sleep and/or performance. One such concept to aid improvement in athlete sleep quality is through sleep extension, more commonly known as napping or 'sleep banking' (Leger 2008, Mah, 2011, Poussel *et al.*, 2015, Thornton *et al.*, 2016).

Sleep extension reduces the pressure to sleep. Miler and Cotes (2009) reported the best timing for naps varies according to individual sleep need, stability and timing of sleep/wake schedules, morning-eveningness tendencies, and quality of sleep during the preceding night, quality of sleep during the nap or amount of prior wakefulness. Naps should generally be between 10' and 30' with shorter naps having a more immediate effect and longer naps being beneficial, but the benefits taking longer to take effect so as to overcome sleep inertia (Milner & Cotes, 2009). Sleep inertia being a reduced ability to think and perform upon awakening and it is thought to mainly occur in the longer naps due to a higher frequency of slow wave sleep (stage 4) (refer to Chapter 3). The best time to have a nap can vary depending on circumstances, opportunity, daytime sleepiness and motivation. However, in terms of circadian rhythms, the most likely time to nap is in the afternoon body temperature nadir, generally between 1500 - 1700 (Milner & Cotes, 2009) and to maintain the nap length to between 30 or 90 minutes in order to stay within the lighter sleep stage aspect of the generic 90 minute sleep cycle.

A study often reported for athletic performance and sleep extension is Mah, (2011) who observed sleep extension in a group of collegiate basketball players who were subjected to extended sleep over a period of 5-7 weeks and who subsequently displayed improved performances and mood ratings. One must note however that there was no control group and these subjects were collegiate athletes, thus not elite and likely to have poor sleep as a consequence of college life and any intervention to improve sleep would potentially have benefits.

Nonetheless wider sleep management strategies including napping have been shown to be beneficial. Appetitive napping in non-sleep deprived groups has been shown to have benefits in subjective (e.g. ratings of sleepiness) and behavioural measures (e.g. mood) and immune system function (Faraut et al., 2011). In elite athletes it is advised that daytime naps may be beneficial due to their known benefits in increasing alertness and alleviating daytime sleepiness for subsequent training sessions, without being detrimental to night time sleep. In short, naps can potentially benefit athletic performance (Leger *et al.*, 2008, Milner & Cote, 2009, Mah *et al.*, 2011, Poussel *et al.*, 2015, O'Donnell, et al., 2018). Similarly, napping has been shown not to affect nocturnal sleep (Pilcher *et al.*, 2001). However, whilst the overall benefit of napping is likely to be an interaction of factors (Milner & Cotes, 2009), we still do not have definitive information as to the specific psycho-physiological benefit(s).

With regard to events where athletes necessitate a nap due to competition demands, e.g. ultra-endurance events, sleep extension strategies become paramount. Poussel *et al.* (2015) reported ultra-endurance runners actively incorporated sleep management strategies into their pre-race or race routines of an ultra-endurance event and this correlated with the number of finishers of the event. Runners who adopted a sleep management strategy based on an increased sleep time the night before the race completed the race faster ($P = 0.0258$), than those who trained for sleep deprivation ($P = 0.0258$). Similarly, Leger *et al.* (2008), observed sleep debt and performance in sailors in an endurance event and concluded final rankings in the race related to the sleep management strategy of the participants.

To surmise, as a concept, sleep extension is underexplored and we reported in our review (Gupta et al., 2016) that while daytime napping appears to be a common compensatory strategy used by athletes, there is little evidence that naps are strategically integrated into training regimes. Other areas included in optimal sleep management programmes would include education of sleep hygiene (refer to Chapter 6 and appendix 4), a collective term for sleep systems (bed, mattress, pillow etc.), sleep practices and a general approach to the act of 'going to sleep'. In short, elite sport could benefit from programmes of athlete sleep education and management with a recognition for the individualised nature of sleep. Indeed, Pitchford *et al.*'s study (2016) observed a change in training environment and the effect on athlete sleep quality in elite Australian Rules football players when comparing home and training camp environments. Specifically, they reported that the training camp environment compromised players' sleep quality due to significantly increased time in bed, without an increased total sleep time. Moreover, individual players, with higher home sleep efficiency, experienced greater reductions in sleep efficiency on training camp. Collectively, this emphasised the need for Sports Science practitioners to take responsibility to work collaboratively with sports to create individual athlete sleep strategies and interventions, in preparation for training or competition scenarios. This can also be highlighted through my personal observations in the fatigue management projects I have conducted and supervised and are described in Chapter 6 alongside a section on 'optimal' practices.

4.6 A multidisciplinary approach

For sleep, and associated movement behaviour, to be explored within a particular sport, a challenge to multi-disciplinary practitioners is convincing high-performance athletes and coaches that capturing objective data about their sleep (and movement behaviour) characteristics and quality is of benefit to performance. Further, given the individuality and specificity of sleep, means the generic advice and education given to athletes can be problematic. Certainly, due to a lack of direct clinical assessment and reasoning as to its effect on performance, or vice versa, high-performance coaches and athletes can remain dismissive and uneducated on the importance of fatigue management. Frustratingly, the individual responses to sleep can make coaches wary of investigating athletes' sleep if the results mean adjusting training programmes in an already crowded training and competition calendar. Reasons for this are hard to decipher, with possible explanations being logistical, financial or coaches fearing the unknown consequences in changing training programmes. Consequently, obtaining 'buy in' from coaches and athletes can be problematic.

Parallel to this is the fact that the mystification of 'sleep' and the combination of science and medical fact mean that, in academic terms, no single discipline 'owns' sleep and it is therefore examined within multiple academic fields. Nonetheless, I present the challenge that despite sleep and associated movement behaviour being less well understood as a physiological process than, for example, gaseous exchange, it remains an individual biological entity and with a greater understanding and normative data from individual athletes we will be able to understand athlete responses better and establish normative data of elite athletes in fatigue management. Further, one cannot ignore coaches and athletes' general subjective perception that good sleep makes a difference to performance and despite there being no direct scientific reason for sleep, in order to be an effective practitioner, it is a concept that should be investigated scientifically within the athletic population.

Nevertheless, I am not proposing improved sleep will be the unique factor in ensuring athletes win a gold medal, but I am highlighting that the single performance aim as coaches, practitioners and most importantly athletes, is to ensure marginal losses are minimised to potentiate a win and good fatigue management can negate such losses. Additionally, the individual diversity of sleep requires a multidisciplinary approach to finding solutions involving interventions to improve and manage athletic sleep and performance. This necessitates the multidisciplinary team having a full understanding of sleep and its biphasic relationship with performance. This is where the physiologist can take responsibility and ownership of the measurement, assessment and subsequent interventions for fatigue management as an impact factor on a sport's what it takes to win model. Starting from the fundamental principle that sleep is predominantly a physiological process, as described in Chapter 3, the physiologist can then lead the process and encourage deeper thought from other disciplines as to possible interventions to enhance sleep or movement behaviour, with a view to having a concomitant effect on training and performance. Therefore, as applied physiologists within the high-performance sport arena, we should recognise the importance of capturing data on this daily phenomenon and the necessary collaboration with the sports and other Sports Science and Medicine disciplines when interventions to improve individual athlete sleep quality are required. This can then allow physiologists to facilitate thorough and correct investigations and intervention planning. Equally, the type of work required to perform fatigue management assessment is typical of that of a physiologist, thus, monitoring sleep and daily activity is in keeping with the role.

Although in these circumstances of multi and interdisciplinary collaborations, it is important that physiologists recognise professional boundaries and that, whilst they can provide the quantitative and qualitative data to exemplify there is an issue with sleep and identify primary causes, they cannot necessarily provide the technical knowledge for a particular intervention. This is where interdisciplinary collaborations are fundamental to the athletes as the consumer and beneficiary of the Sports Science and Medicine support.

4.7 Summary

This chapter has provided information regarding contemporary sports science literature on sleep, strategies to combat poor sleep and suggestions for who leads a fatigue management project within a Sports Science and Medicine team. Poor sleep can present a problem to athlete's in that it is a single entity but has a multifactorial impact on an athlete's ability to deliver quality training sessions and subsequent performances. Sleep quality and structure among elite athletes are challenged by the physiological and emotional stress of training and competition, and the circadian demands of integrating training programmes into athlete lifestyles. Combined with training stress, poor fatigue management will impact on an athlete's overall health, wellbeing and performance through affecting propensity and recovery from injury and illness and preparation for associated training adaptations and adherence. Collectively all of the factors described in this chapter have a relevance to training and the subsequent impact on performance.

To combat risk factors for disturbed sleep in high performance sport, as practitioners, we need to provide fatigue management strategies (e.g. sleep banking) for sleep and performance maintenance, improvement and enhancement. I feel it is therefore the responsibility of Sports Science practitioners to investigate athlete norms and provide such strategies. As discussed in Chapter 1, in an industry governed by marginal gains, with such small differences between podium performances, there is a need to identify and scrutinise 'What it Takes to Win' models and assess the variables which *impact* on an athlete's ability to train and compete. In this chapter I have presented that fatigue management, through sleep and associated movement behaviour, is an example of such a variable. Certainly, it is an evolving concept in the field of high performance sport which will ultimately help to pioneer and address the critical determinants of performance more successfully. Practical examples of using fatigue management assessment in this manner are presented in Chapter 6 and the simplicity of being able to gather quantitative data on sleep and associated movement behaviour variables are presented in the next Chapter.

Chapter 5. Methodologies to Measure and Assess Sleep and Movement Behaviour

5.1 Introduction

Whilst many projects reported in this thesis followed a quantitative methodology, there was scope for qualitative methods to supplement the quantitative studies and add substance to the findings. Therefore, a mixed methods design was employed to capture all the relevant data. Qualitative methods were discussed previously in Chapter 2 and this chapter will focus on the quantitative methods (objective and subjective) employed to capture sleep and associated movement behaviour data, ahead of further Chapters reporting projects utilising such methods.

5.2 Sleep quantity and quality

As outlined in Chapter 4, it is important to describe and bring clarity to what is meant by sleep quantity and quality. This is even more important as sleep becomes more popularised and modern day technologies provide commercially available equipment to measure sleep *quantity* (duration) and *quality* (disturbances) (Galambos *et al.,* 2011, Ohayon *et al.*, 2017). In terms of *quantity*, The National Sleep Foundation (NSF) panel for updated sleep duration recommended 7-9 hours of sleep for adults (18-64 years) with variables such as time to bed (TTB), time in bed (TiB), get up time (GUT) and total time asleep (TTS) observing sleep quantity (Hirshkowitz *et al.*, 2015). The National Sleep Foundation (NSF) panel consensus on sleep *quality* was that measures such as sleep latency (SL), number of awakenings greater than 5 minutes, wake after sleep onset (WASO), sleep efficiency (SE) and fragmentation index (FI) yielded good indicators of overall sleep quality (Hausswirth *et al.* 2014 and Ohayon *et al.*, 2017). Diurnal activity can be assessed by time spent immobile (%) and mobile (%) during waking hours. Predominant sleep variables are outlined in Table 5.1

Table 5.1. A description of sleep variables measured (modified from Leeder *et al.*, 2012 & Gupta *et al.*, 2016)

Sleep Variable	Description
Time to bed (TTB) (hr:mm)	The time the actiwatch recognises time to bed determined by pressing button on watch or watch detects 'lights out'
Time in bed (TIB) (hr:mm)	The total elapsed time between the "Lights Out" and "Got Up" times
Actual sleep time (AST) (hr:mm)	The total time spent in sleep according to the epoch-by-epoch wake/sleep categorisation
Get up time (GUT) (hr:mm)	The time the actiwatch recognises get up time determined by pressing button on watch or watch detects 'light'
Wake after sleep onset (WASO) (hr:mm)	the amount of time individual spends awake, starting from when they first fall asleep to when they become fully awake and do not attempt to go back to sleep
Sleep period time (SPT) (hr:mm)	The time elapsed between the first onset of sleep and the final awakening
Sleep efficiency (SE) (%)	Total sleep time expressed as a percentage of time in bed: total sleep time/time in bed x 100. Provides a sensitive metric for estimating sleep quality. SE below 85% indicated a disorder. Can be assessed from instrumental or subjective estimates (of total sleep time) Actual sleep time expressed as a percentage of time in bed
Total sleep time (TST) (min)	The total amount of time spent asleep whilst in bed (SPT-WASO)
Sleep latency (SL) or Sleep onset latency (SOL) (min)	The elapsed time between "Lights Out" and sleep onset
Sleep profile (SP)	Generally, the reported sleep onset latency, total sleep time and sleep efficiency
Fragmentation Index (FI)	A measure to the extent to which continuous sleep is interrupted by episodes of wakefulness. It is an indication of the degree of fragmentation of the sleep period, and can be used as an indication of sleep quality (or the lack of it). Sleep fragmentation is reflected in the duration and/or frequency of episodes of WASO It is the sum of the mobile time (%) and the immobile bouts <=1min (%).
Immobile time (%) (IT)	The immobile time expressed as a percentage of the assumed sleep time
Mobile time (MT) (%)	The mobile time expressed as a percentage of the assumed sleep time

5.3 Quantitative methods for sleep quality, quantity and movement behaviour

Whilst there are different sleep and waking movement behaviour projects to be described in Chapter 6, the rudimentary methodology remains identical for all projects. Any differences in logistical methodologies will be reported within each project report (Chapter 6).

5.3.1 Sleep measurement and assessment

Two common methods in terms of sleep quality measurement and analysis exist, polysomnography (PSG) and Actigraphy. Polysomnography (PSG), is regarded as the 'gold standard' measurement of sleep architecture and quality, although it is limited in its ability to measure large numbers due to being labour intensive and requiring specific skills in electrode placement and analysis of outputs. Also, PSG can be expensive, and is often used primarily for assessing clinical sleep disorders. Specifically, it can record body functions such as brain activity (electroencephalogram, EEG), eye movements (electrooculogram, EOG), muscle activity (electromyogram, EMG), and cardiac activity (electrocardiogram, ECG) (Halson 2014). Information on sleep that can be obtained from PSG analysis includes, but is not limited to, total sleep time (TST), sleep-onset latency (SL), wake after sleep onset (WASO), sleep efficiency (SE), sleep fragmentation index (FI), number of awakenings, time in each sleep stage, and sleep stage percentages (Halson 2014).

Whilst PSG provides the most valid and reliable marker of sleep architecture and is recognised as the gold standard methodology, Actigraphy is a more ecologically valid field measure of sleep quantity, quality and activity (Ekblom *et al.*, 2012, Lambiase *et al.*, 2014) and therefore, for the purposes of my projects, allowed sleep and movement behaviour to be assessed in an athlete's natural environment.

There are several actigraphy units on the market and their use in physical activity and sleep medicine literature is common (Sedeh & Acebo 2002, Ekblom *et al.*, 2012, Lambiase *et al.*, 2014). My preferred method of data collection, (and therefore advised to other practitioners in the UK high performance industry), is through the use of an Actiwatch (Respironics

Actiwatch 2 (AW2), Philips Healthcare, UK). It is these units which were predominantly used in the various projects described in Chapter 6, as at the time of the projects, these units were routinely used by sleep researchers I had sought advice on sleep assessment from.

Actigraphy is a popular choice for assessing sleep (and activity levels) in the field as it is validated against the gold standard PSG measurement and is a simple, non-invasive method of monitoring human rest/activity cycles. Sadeh (2011), reported in a review of the role and validity of actigraphy, that it has reasonable validity and reliability in normal individuals with relatively good sleep patterns. Reportedly, it has accuracy with PSG of up to 80% for total sleep time and sleep efficiency in sleep disorder patients (Kushida *et al.* 2001) and is commonly used in sleep literature. Whilst the two methods cannot directly be compared due to methodological differences, actigraphy at least is the preferred field measure over PSG due to its relative ease of use and cost effective benefits, not just financially, but also to the subject's time (in my case the athlete). Other advantages of the actiwatches are their discreet and compact design, making wearing the device easy and unobtrusive. Its deployment involves a small actigraph unit (43 mm x 23 mm x 10 mm and 16 grams), which houses small uniaxial accelerometers, (preferably 3 axes to be medically valid against PSG), which are usually intended to be worn on the wrist of the non-dominant arm to measure gross motor activity. The placement on the wrist makes it possible to study low-intense physical activities as well as monitoring physical activity during sleep for sleep duration and quality assessment (Ekblom *et al.*, 2012).

Sedeh & Acebo (2002) commented some disadvantages to the actigraphy technology in that its validity has not been established for all scoring algorithms or devices (typically 2-axis devices) or for all clinical groups. Secondly, it is not sufficient for diagnosis of sleep disorders in individuals with motor disorders or high motility during sleep. Further, in sleep onset studies a spectrum has been presented for the onset of sleep and is presented in Figure 5.1. Tryon (2004) reported that actigraphy is theoretically associated with Sleep Onset Spectrum phase 1, whereas PSG is theoretically associated with Sleep Onset Spectrum phase 2, thus, making direct comparisons in sleep onset difficult. This difference is more pronounced in those with insomnia than normal sleepers.

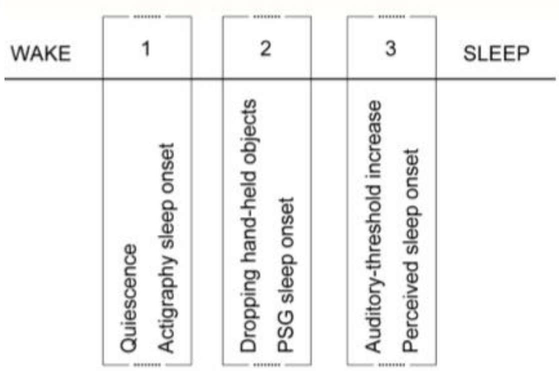


Figure 5.1 Three phases of the sleep-onset spectrum between wake and sleep. The spectrum displays the differences in the point of identified sleep onset from 3 methods of recording sleep. Actigraphy identifies sleep onset earlier than Polysomnography (PSG) and subjective recordings across the wake-sleep spectrum (adapted from Tryon, 2004).

Finally, actigraphy relies on algorithms and, as with any computer generated outcome, the use of computer scoring algorithms without controlling for potential artefacts can lead to inaccurate and misleading results. Nonetheless, the American Academy of Sleep Medicine accept validated actigraphs as an acceptable measure of total sleep time in certain circumstances (Byrne, 2017).

For this thesis the actigraphy unit employed was the Respironics Actiwatch 2 (AW2) (Philips Healthcare, UK). This is a small hand-held device housing a tri-axical accelerometer to continually record illuminance, movement, and event marking.

Of note, some studies in the academic literature, (that involved elite athletes using actigraphy), found lower sleep efficiencies in elite athletes, characterised by a longer time in bed, higher wake time after sleep onset, sleep onset latency and sleep fragmentation (Leeder *et al.*, 2012, Gupta *et al.* 2016). This is in comparison to studies using athlete self-assessment of sleep where an overestimation of sleep duration was reported (Caia *et al.*, 2017).

5.3.2 Movement behaviour measurement and assessment

As discussed in Chapter 4, the capture and analysis of the daytime activity volume (i.e. movement behaviour) in elite athletes is not widely reported, if collected at all, despite a plethora of data existing in physical activity domains. The same field-based tools used to measure nocturnal sleep characteristics and quality can also provide information on diurnal movement behaviour through activity volume and pattern assessment (Lambiase *et al.*, 2014). As with sleep, rest-activity profiles are calculated from algorithms on activity volume in the actiwatch software (Respironics, Surry, UK). Variables such as activity count (unit to indicate if the subject is asleep or awake), percentage immobile time and percentage mobile time can then be analysed. Essentially, all time is scored as awake unless the activity counts from the monitor are sufficiently low to indicate that the subject is immobile.

Although field measures to assess sleep have not proven to be as valid or reliable in measuring the *intensity* of activity, they are acceptable for measuring physical activity *volume* i.e. counts per minute or counts per day (Routen, 2014). Specifically, the Actiwatch AW2 model (Respironics Actiwatch 2 (AW2), Philips Healthcare, UK) is sufficient as it provides data on activity volume.

Another advantage of using actigraphy to assess movement behaviour is that it provides, through a single device, a direct assessment of sleep and movement behaviour in free-living settings. For both conditions the actiwatch uses similar methodology to detect accelerations in body movement and this both minimises the cost and participant burden during data capture phases (Lambiase *et al.*, 2014).

Therefore, the use of actiwatches is an ideal approach for assessing the pattern of such rest-activity profiles in elite athletes, as the intensity of activity or rest is not the purpose of the exercise, more the objective assessment of the equilibrium between rest and recovery during waking hours. That is the percentage of the amount of time an athlete spends being mobile or immobile during waking hours. As sleep-wake recording is more reliably obtained, a daily sleep diary recording self-reported time to bed and get up time is also useful to have (Fietze *et al.* 2009). The actiwatches record sleep when the two conditions of low activity counts and subjective reported time to bed are satisfied simultaneously (Halson 2014) and this can be verified through self-reported measures.

In summary, I would be confident in using the Actiwatch wearable technology for assessment of sleep and activity (movement behaviour) in the field. Their validity against PSG for sleep variables is good (above 80%) and their assessment of 'activity counts' is a more practical assessment of movement behaviour than other available technologies which, for example, rely on indirect measures of energy expenditure. Indeed, wearables estimating energy expenditure have been shown to be less valid compared to gold standard measures of energy expenditure such as a metabolic chamber or doubly labelled water (Murakami et al. 2016). Similarly, the end user, in this case the athlete, can relate to 'activity counts' as a marker of their level of activity (e.g. low, medium or high) much more readily than measurements of energy expenditure. Of further note, is the fact that the actiwatch displays representative and quantifiable information regarding sleep and movement behaviour compared to other measures, such as quality and intensity of activity, which are much more subjective, individualised and to a certain extent rely on a person's technique for a particular activity. Therefore, other options for presenting sleep and movement behaviour data in a valid and athlete friendly manner were limited.

5.4 Actigraphy methodology

Actigraphy is my preferred method of data collection for sleep and movement behaviour for reasons already outlined. When using actigraphy the actiwatch is typically worn on subjects' non-dominant wrist 24 hours a day for approximately 14 days at an epoch of 1 minute. 14 days is the advised minimum length of wear to establish 'normal' sleep patterns (Morgan 2013). If the watch is to be worn for longer than 14 days, the epoch needs to be increased to two minutes to allow longer battery life. This doesn't affect data collected other than the collection of the variable 'Fragmentation Index' (a measure of restlessness). This is recorded via the actiwatches accelerometer hence, conserving battery life compromises recording this variable. However, fragmentation index is not a fundamental sleep variable to be measured, so can be omitted if required without affecting overall data collection of key sleep and movement behaviour variables.

For all projects reported in Chapter 6, nocturnal and diurnal sleep was captured along with diurnal activity patterns. The time between switching the light off, to sleep and wake-up was marked by pressing a single button once on the face of the actiwatch (Sedeh 2011). Sleep structure was assessed by discriminating; time to bed (TTB), time in bed (TIB), get up time (GUT), total sleep time (TST) and sleep latency (SL). Sleep quality was determined as sleep efficiency (SE) and fragmentation index (FI) in accordance with Hausswirth *et al.* (2014) and diurnal activity was assessed by time spent immobile (%) and mobile (%) during waking hours. Variables are described in Table 5.1

All variables were derived from the Actiwatch software algorithm. Sleep and daytime activity characteristics were assessed in both domestic (UK) and overseas (OS) environments, including sea-level (SL) and altitude (A) training camps. For oversees analysis, sleep and activity markers were recorded from day two to allow for travel transition and time zone shift.

5.5 Subjective assessment of sleep

In terms of subjective assessment of sleep there are five questionnaires (detailed in Chapter 6) which exist that can provide a spectrum of assessment of subjective perceptions of sleep (Horne & Osberg (1976, Buyesse *et al*., 1988, Johns, 1990). The primary benefit of such questionnaires is that they are largely single answer only, so athletes are not laboured with having to complete them daily. The questionnaires are primarily retrospective with participants reporting on typical sleep patterns, disturbances, or behaviours (e.g., sleep habits/hygiene, sleep quality) over a specified time period (e.g., 1 week, 1 month) (Lewandowski, *et al.,* 2010). The broad spectrum of questionnaires and their individual focus means a comprehensive subjective assessment of an individual's sleep from sleep practices and quality through to self-perception of sleep, can be ascertained reasonably efficiently. Whilst limited athlete specific sleep questionnaires exist (e.g. Samuels *et al*., 2015, Driller *et al*., 2018), I felt advising practitioners of an array of established subjective clinical sleep tools (questionnaires), which provided a breadth of information of an individual's sleep, was more impactful than a single athlete specific questionnaire.

Questionnaire measures can be used alone or in conjunction with other sleep assessment tools to provide a comprehensive examination of sleep (Lewandowski, *et al.,* 2010). A principle advantage being that relative to objective measures, subjective sleep instruments have been the most practical tools used to identify sleep problems and assess responses to interventions in both research and clinical settings (Ji & Liu, 2016).

Disadvantages of such questionnaires are that you are relying on an individual's perception of their own sleep. This is problematic as often subjective assessment of one's sleep differs from objective measures with the benefit of enough sleep verses insufficient being a perceptual one. Further, in terms of athletes, asking them to complete questionnaires' is another demand on their time and can be interpreted as being too intrusive. Whilst these weren't specifically employed in my work with elite athletes' they were utilised as part of the PhD I was supervising and are described in Chapter 6 as part of a methods of optimal practice section.

Through subjective and objective field measures, sport science and medicine practitioners can now measure high performance athletes' sleep and waking movement behaviour in free-living settings. As a result, practitioners can now quantify recovery time during wakeful hours, investigate sleep hygiene practices (i.e. all environmental and behavioural aspects preceding sleep) and quantify the quality of their sleep. Therefore, sleep can now be characterised in the environment of the person being assessed. This has implications for not only the recovery practices of high performance athletes, but also their susceptibility to illness, injury and overtraining and consequently time lost training. Further impact will be to the interventions imposed through science and medicine practitioners e.g. nutrition, medicine and performance lifestyle and the impact of fatigue management on 'What it Takes to Win' models. Examples of projects within sports summarising some of the above impact and effectiveness of fatigue management practices are outlined in the next Chapter.

Chapter 6. Fatigue Management Projects within the UK High Performance Sport Industry and Methods of Optimal Practice

6.1 Introduction

Chapter 5 outlined the quantitative and qualitative methods of measuring and assessing athlete's fatigue management through their sleep and movement behaviour. This chapter presents a narrative of my fatigue management strategy within the UK high performance system; specifically, within the EIS, how knowledge has been disseminated and also provides executive summaries of pioneering fatigue management projects that have been conducted in the field of high performance sport. It is a pragmatic approach to providing a mixed overview of some perspectives on sleep from a high-performance setting. Such projects are scrutinised for the impact on sports programmes and the influence on and benefit to the practitioner leading the projects. Finally, this chapter will also provide some methods of optimal practice for practitioners conducting fatigue management projects. This will be followed in Chapter 7 by a summary of the thesis, conclusions and future recommendations for delivering an effective fatigue management strategy in elite sport.

One of the principle sports used to exemplify some of my fatigue management projects and a sport that contributed greatly to my development as a physiologist and leader within UK Sports Science is British Rowing. They have consistently, since lottery funding began in 2000, been in the top five most funded sports in the UK Sport system (Table 6.1). In terms of medals, at the London 2012 Olympic Games, British Rowing experienced their most successful Olympics of all time where the team won a record nine medals after qualifying boats for 13 of the 14 events held at the Olympic rowing regatta at Eton Dorney. The medal haul included four gold, two silver and three bronze medals with Great Britain finishing as the top rowing nation for the third successive Olympic Games in terms of total medals. They successfully defended this position in the Rio 2016 Olympics and, in addition, have achieved first place in the medal table at successive World Rowing Championships through 2007-2015 (total medals won).

Table 6.1 UK Sport's top five most funded Sports during the Sydney to Tokyo Olympiads (UK Sport, 2017)

Sport/Olympiad	Sydney*	Athens*	Beijing^	London^	Rio^	Tokyo^
Athletics	£10,600,000	£11,400,000	£26,513,000	£25,148,000	£26,824,000	£27,136,245
Cycling	£5,400,000	£8,600,000	£22,151,000	£26,032,000	£30,565,816	£25,980,427
Rowing	**£9,600,000**	**£10,600,000**	**£26,042,000**	**£27,287,000**	**£32,622,862**	**£32,111,157**
Sailing	£5,100,000	£7,600,000	£22,292,000	£22,942,000	£25,504,055	£26,231,379
Swimming	£6,900,000	£6,400,000	£20,659,000	£25,144,000	£20,795,828	£21,742,914

** Figures for the Sydney and Athens Olympiads relate just to Podium level funding. During that time, the home nation sports councils were responsible for supporting Development and Talent level activities*

^ On 1 April, 2006 UK Sport became responsible for all Performance funding from Talent to Podium and these figures reflect that total package. These figures also include the cost of Sports Science and Medicine provision not previously incorporated as part of a sport's funding award

6.1.2 Athlete population

As described in Chapter 2, the 'eliteness' of the athlete population used throughout this thesis is confirmed as 'successful elite' according to a model established by Swann *et al.* (2015) and described earlier in Chapter 2.

The majority of data provided in the reports of Sports' projects stems from the British Rowing Team (BRT) population as I had a principal role in their Sports Science and Medicine team for three Olympic/Paralympic cycles. In addition, the impact of evolving the fatigue management concept to the UK high-performance industry and an illustration of the success and refinement of the work with British Rowing, will be exemplified through projects with other sports. In all cases, the data collection and analysis of sleep and waking movement behaviour variables formed part of my daily work programme either with the BRT or as a technical lead/PhD supervisor within the EIS.

6.2 Fatigue management pilot work – British Rowing

As part of British Rowing's preparation for London 2012, I had the idea to capture and analyse rowers fatigue management through sleep characteristics (quantity and quality) and movement behaviour profiles. This formed part of my role as British Rowing's senior physiologist and as technical lead for the EIS. Therefore, it served as an initial introduction of fatigue management to my work programme and ultimately the EIS and wider industry. My assessment of rowers' sleep and movement behaviour was supported by findings in the literature reporting rowers' as having the lowest total sleep times and shortest sleep onset latencies, but highest sleep efficiencies (time in bed/time asleep) compared to a cohort of other athletes (Leeder *et al.*, 2012).

Below is a brief description of the pilot work I completed. A specific description of my more comprehensive British Rowing projects relating to fatigue management are provided further in this chapter. This is also where executive summaries of other Sports' projects that I was involved with are presented.

In 2010, the concern within the British Rowing science and medicine support team was that in the preparation phase for the London 2012 home Olympics, rowers' external commitments to training (e.g. media demands) were, if not managed correctly, potentially a detriment to training and ultimately performance. Therefore, rowers' fatigue management, through assessment of sleep characteristics and movement behaviour profiles, were identified as a useful means of capturing data on the rowers' challenges and commitments external to the training environment.

I conducted my preliminary work on selected rowers over a period of two weeks. Rowers were selected by myself and the British Rowing's Chief Coach (Senior Men) as those in the Senior Men's squad who were fully fit, (i.e. achieving the training programme daily) and also, highlighted by the Chief Coach, going to attend upcoming training camps. There was no prior sleep or movement behaviour data on any of the rowers. I had a tiered approach to capturing data and analysing the rower's sleep and movement behaviour, as a particular challenge was the limited number of actigraphy units I had available to me versus the number of rower's to be assessed. I prioritised the order of rower's to be assessed through my own criteria of need (e.g. those athletes who consistently reported subjective poor sleep) plus discussions with the Chief Coach (Senior Men).

Quantitative assessment was accomplished using standard actiwatches (for methodology refer to Chapter 5). Using the actiwatches to capture a rudimentary assessment of rowers' fatigue management, allowed me to objectively assess their global recovery strategies. Through this pilot project, I demonstrated the practical reality that limited normative objective data existed on elite rowers' (and wider athletic populations) sleep characteristics or movement behaviour. I also established a lack of athlete/coach knowledge and awareness of fatigue management techniques in relation to sleep and movement behaviour.

Consequently, this initial bespoke pilot project in an isolated sport, highlighted that, although an unknown and limited explored entity, athlete sleep and associated movement behaviour should be routinely assessed. This point is enhanced when I consider sleep is frequently used as a subjective marker in the analysis of an athletes' well-being when I am monitoring their responses to training and competition. This opinion was enhanced through communications at the 2013 American College of Sports Medicine Annual Conference. Here I listened to several presentations on sleep and was motivated to observe that a common theme throughout was that there were not enough specific studies on sleep and athletic performance and that this was the next 'theme' in sleep literature which required particular attention (Trek, Colwell and Esser 2013). This has been substantiated through a recent survey which my PhD student performed and found only 40 % of 345 Olympic and Paralympic athletes reported having received any education on sleep (Gupta, 2015). Reasons were that sleep is traditionally not explained to athletes in terms of architecture, behaviour and measurement techniques.

Therefore, the initial pilot project with British Rowing, parallel with discussions in the field of academic sleep literature, set the scene for me to further pioneer and investigate fatigue management knowledge, strategies and impact within the UK high performance sport industry. Whilst other physiological variables were objectively monitored, I felt quite strongly that fatigue management was an area to be captured and explored in the elite athletic population.

6.3 EIS fatigue management research

Following on from my initial work with British Rowing, the overall TeamGB success of the 2012 Olympics and through communications with peers and academics, I suggested that formal research channels within the EIS should be directed towards the area of fatigue management and athletic performance (i.e. a PhD focusing on sleep and athletic performance). At the time I was part of the leadership team recruiting the second cohort of the EIS physiology team's PhD model as part of the physiology strategy for the 2016 Rio Olympic cycle. Securing the generically titled 'Sleep and Athletic Performance PhD', involved presenting my ideas, as evidenced by my pilot studies, discussions at international conferences and with professors within sleep academia, to the then EIS Director of Sport Science. My idea was supported as firstly, I could demonstrate that whilst high performance sport practitioners, coaches, athletes and academic research groups recognise sleep as a critical biological function, rarely had there been a focus on capturing data to inform athletes about their fatigue management strategies. Secondly, there was limited academic research existing regarding sleep, associated movement behaviour and athletic performance, so essentially it was an 'unknown' area in the applied sport science and medicine industry, yet it had a potential impact on 'what it takes to win' factors. As discussed in Chapter 4, as early as the 1970's sleep and athletic performance were analysed but not to the extent nor level of detail required. Also, I could see through my pilot work and discussions at an international conference where I also presented on an aspect of sleep and athletic performance[7], that there would be a demonstrable benefit to training an performance through educating athletes and coaches on fatigue management strategies. Example strategies being improved sleep systems and

[7] I presented at the America College of Sports Medicine Conference (ACSM 2013) on 'Sleep Characteristics and Quality from Domestic and Overseas Training Environments in Paralympic Rowers' (Appendix 3).

hygiene, nocturnal sleep, sleep extension, or combating circadian rhythm disruption. Subsequently, I was able to demonstrate such benefits to training and performance and examples of this are provided later on in this chapter and in Chapter 7. Therefore, I was successful in acquiring funding for the 'Sleep and Athletic Performance PhD' within the EIS one of seven physiology PhD's within the EIS), and plans were established for an EIS PhD studentship (2013-2018), of which I was a co-supervisor.

Critical to the success of the EIS 'Sleep PhD' was finding a suitable external supervisor. It was crucial I found an academic who was not only respected in the area of sleep research and could provide appropriate counsel to the successful applicant, but who also understood the world of high performance sport. This process was a learning curve and at times akin to finding a needle in a haystack given academics with a grasp of what high performance sport involves and the realities of working as a practitioner in the applied field are scarce. Fortunately, I was successful in collaborating with Professor Morgan of Loughborough University who was an outstanding academic supervisor candidate. Having had a career-long research interest in human sleep, in 2005 he set up the Clinical Sleep Research Unit at Loughborough University where he is currently Professor of Psychology and Director of the Unit. He specialises in the origins, assessment and treatment of insomnia-type sleep disorders, and inter-relationships between sleep quality and elite sport. His publications include over 150 scientific papers and several books and he is a Fellow of the UK Academy of Social Sciences, an associate Fellow of the BPS, has served as an advisor to the UK Medicines and Healthcare Products Regulatory Agency (MHRA) and National Institute for Health and Clinical Excellence, and is an Associate Editor of Behavioural Sleep Medicine. Crucially, he also had previous experience of working with high performance sport on the topic of sleep.

Professor Morgan was integral to the establishment and success of the EIS sleep and athletic performance PhD and we successfully recruited a PhD candidate in July 2013. From their research, several innovative studies involving sleep and elite athletes have been achieved alongside a leading review article produced for the Sports Medicine journal (2016).

Parallel to my establishment of the EIS PhD in sleep and athletic performance, was the fact that applied research in the sports science industry had critically evolved over the last three decades. Consequently, as presented in Chapter 1, there have been significant developments in the impact of sports science and practitioner input within Sports' performance programmes. I believe the assessment of athletes' fatigue management, through sleep and associated movement behaviour data, is a product of this surge in sports science practitioner support to high performance sport programmes.

6.4 Dissemination of knowledge

In evolving the new concept of fatigue management, one of the first steps was to disseminate knowledge as to what with and why we were promoting and researching this concept. Given that my proactiveness in developing a method of fatigue management was being extremely well received by coaches and athletes and likely making a difference to their performance, alongside supervising the EIS 'sleep and athletic performance' PhD, it was important to engage and educate GB Sports and their practitioners as widely and quickly as possible. This proved quite a change orientated issue, particularly due to the fact that this was not a topic traditionally allied to the area of physiology. Coupled with the reality that up until the inception of the EIS PhD, there was very little attention placed on the concept of fatigue management. Consequently, dissemination of knowledge for awareness and development of practitioners, athletes and coaches was essential in the initial stages of the project.

The preliminary platform for introducing the concept of fatigue management, through sleep and movement behaviour analysis, to the UK high-performance sport network was at the 2013 EIS National Conference. Here invited delegates from Home Country Sports Institutes (HCSI), National Governing Bodies of Sport (NGB) and EIS practitioners were in attendance. All EIS staff were invited to submit forum ideas to present to conference delegates and I successfully applied to present a forum to introduce the concept through a forum entitled 'Sleep and athletic performance: a multidisciplinary perspective'. The session aimed to describe and educate multi-disciplinary practitioners as to the principle areas of interest for fatigue management from a psycho-physiological perspective. Further, the aim was to develop awareness of the technologies available to analyse elite athletes' sleep and associated movement behaviour and update the audience on current work within the institute. The expectation being this would enhance the impact we had as a network of multidisciplinary practitioners on fatigue management strategies, through gaining consistency of message, collaboration and quality assured practice, coupled with development of technology utilised.

The impact of the forum was twofold. It encouraged dialogue about the topic between practitioners within the HCSI, NGB's and EIS and increased the demand for expertise and advice on sleep from 2013 onwards. Given the following year involved both Winter Olympics and Commonwealth Games (2014), several Sports competing in these events acted upon the forum and requested input to their own fatigue management strategies (e.g. Great Britain short track speed skating and England Netball). These requests also provided an excellent opportunity for the PhD student to efficiently and effectively upskill on methodologies and technologies available to assess sleep and movement behaviour. Specifically, they needed to become proficient in objective and subjective assessment methods, understand sleep data using appropriate software and identify different means of disseminating information back to coaches and athletes e.g. bespoke individual feedback, infographics and generic workshops.

As a follow up to the 2013 springboard forum event, and as a consequence of requests throughout 2014 for 'performance solutions' relating to fatigue management, I decided, a workshop targeting practitioners currently using or planning to use sleep and movement behaviour assessment was warranted. I was particularly mindful at this point that we would receive requests regarding fatigue management strategies for the upcoming Rio 2016 Olympics and Paralympics. Therefore, in 2014 myself and the PhD student presented a one-day workshop with the principle objectives being:

To provide:

1. context to the new area of expertise: fatigue management (sleep and movement behaviour assessment)
2. a broad overview of current research in the domain of 'sleep and athletic performance' (e.g. why it's important, what's missing)
3. practical examples and models of optimal practice for measuring and analysing athletes fatigue management strategies
4. an applied focus to research projects involving sleep, movement behaviour and elite athletes
5. future directions for research into fatigue management and athletic performance

This proved a success in the sense that workshop attendees were positive about the learning objectives achieved and it had upskilled myself and my PhD student in disseminating technical knowledge about sleep and movement behaviour. The workshop also gave me further ideas to evolve the concept within the high-performance sport industry, e.g. recommendations for optimal practice and these are presented further on in the thesis.

During the next phase of the evolution of the concept of fatigue management, I was absent from my EIS role due to maternity leave. However, my co-supervision of the PhD student continued and a principle piece of work we designed and conducted during this time was an online questionnaire (the validated Pittsburgh Sleep Quality Index questionnaire – refer to Chapter 5 for more detail), to all summer and winter Olympic and Paralympic athletes in the UK high performance system. This was an unprecedented piece of work involving good communication skills and negotiating skills with the identified sports lead contacts in order to gain access to the athletes. In all over 400 (183 female) elite British athletes (mean age 26.5 ±0.7) completed the questionnaire from 22 Olympic and Paralympic sports, a monumental achievement in the world of high performance sport. Gaining access to the athletes and having such a high response rate was a result of some of my own professional relationships with personnel in the UK high performance sport industry and a credit to my PhD student, who worked hard to establish good working relationships with the necessary people, in each sport, in order to have them help engage and gain access to the athletes to complete the questionnaire. Principle findings from this piece of work are described further on in this chapter and help to provide current evidence of reported findings relating to elite athletes' sleep.

In 2014, in addition to the PhD research, we ran workshops which were designed using EIS intellectual property and expertise. These workshops were a principle driver as to the increased impact the area of fatigue management was having in the UK high performance sport system. The workshops were designed to educate and disseminate information about the topic of fatigue management to sport governing bodies in preparation for the Rio 2016 Olympic and Paralympic Games. The first, was a workshop to the British Paralympic Association (BPA) entitled; 'Sleep to Win: An Introduction to Sleep Management in Paralympic Sport'. This was conducted three times so as to engage with as many Paralympic sports as possible and aimed to raise the level of sleep literacy across such sports. Topics discussed ranged from 'normal sleep' to 'how sleep influences performance, 'identifying problems: the vulnerable athlete and importantly 'signposting: how to respond to complex problems'. Whilst I was not involved in direct presentation at the workshops (due to maternity leave), it was my contact with Professor Morgan and the introduction of the concept of fatigue management to the EIS which prompted the workshop initiative.

Feedback from the BPA workshops was positive in that the Sports found the information useful and impactful to their Rio Olympic Games 2016 planning. Consequently, this led to many more requests for information regarding fatigue management strategies for Rio 2016 preparations. Therefore, a further initiative to address practitioners with a specific interest in fatigue management strategies was established. This was in the form of a roadshow of workshops, targeting key areas in the EIS network where maximum impact in disseminating information regarding fatigue management strategies could be achieved. The objectives of the workshops were threefold, firstly to upskill relevant practitioners, system wide, in the fundamentals of sleep assessment, basic sleep literacy, and collecting and analysing useful and meaningful sleep data. Secondly, to serve to strengthen the high-performance sport system around the topic of sleep, and thirdly to preserve the time that the 'sleep experts' were spending dealing with athletes for the most challenging, important and impactful cases.

The workshops contained three presentations; 1. understanding sleep, 2. sleep in elite sport: training, travelling and competing and 3. managing athlete sleep: a stepped approach. The presentations were aimed at the Olympic Sports, given that the BPA had previously received a workshop. Feedback from the delegates was positive, the presentations were useful and enabled practitioners to apply their new-found knowledge of sleep to their daily role.

6.4.1 EIS Hierarchy of Needs and Decision Tree

As a consequence of disseminating knowledge around the network regarding fatigue management there was an influx of requests from Sports and their Sports Science and Medicine practitioners for assistance in measuring and analysing their athlete's sleep and associated movement behaviour. This increase in requests for support built momentum over the period of the Rio Olympic cycle and in 2014/15 there were more requests than I and my PhD student could effectively and efficiently deal with. The demand for our knowledge was amplified not only by summer Olympic/Paralympic sports preparing for the 2016 Games, but also by sports involved in the 2014 Winter Olympics and Commonwealth Games. Essentially over a 2 year period (2013-2015) we evolved from a single sport expressing an interest in generic sleep measurement and analysis, to the majority of sports in the UK high performance sport system requesting access to our knowledge. This amounted to approximately 20-25 sports. As a consequence of the increased requests for specific sport related fatigue management knowledge, we not only delivered workshops, but also developed an EIS 'Hierarchy of Needs' which established a process to manage requests for advice on fatigue management knowledge and strategies. Figure 6.1 displays this hierarchical approach designed for the measurement and assessment of sleep and movement behaviour in high performance sport. Fundamentally this is a four-step process ranging from the initial upskilling of practitioners within their Sports with knowledge of how and what fatigue management is, to how to measure and assess sleep and associated movement behaviour and finally to referral to clinical expertise. The EIS Hierarchy of Needs, and Decision Tree (illustrated in Figures 6.1 and 6.2 respectively), also demonstrate the need for flexibility in providing support to practitioners and Sports with regards to sleep and movement behaviour projects. Whilst we had a generic format for the workshops delivered, we had to adapt according to Sports individual requirements e.g. timescales to competition.

In terms of first principles, level one of the hierarchy of needs process focusses on the fact that, in general, practitioners comprehend what the concept of fatigue management is, what sleep and movement behaviour are and how they can impact on what it takes to win factors. In short, practitioners gain an appreciation of normal sleep regulation and its potential impact on 'what it takes to win' factors. Specifically, level one in the hierarchy of needs means physiologists gain absolute understanding of what sleep is and how it is physiologically regulated. An appreciation of other factors governing sleep is also advantageous e.g. psychology. Subsequent levels address the level of measurement and assessment and ultimate requirement for referral for clinical management.

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
• Practitioners in sports equipped to collect appropriate sleep and movement behaviour data and manage basic sleep education and literacy issues • Generic workshop provided to MDT*	• Within a sport poor/vulnerable sleepers are identified and unique sleep challenges explored (i.e. competition, travel etc.) • Objective and subjective analysis of sleep • Comparison with normative data of athletic sleep (database) • Basic intervention workshop provided to a sport • Refer to 'guidelines for enhancing sleep behaviour' advice	• Identified poor/ vulnerable sleepers are equipped with bespoke interventions based on prior assessment • Detailed objective and subjective analysis of sleep • Comparison with normative data of athletic sleep (database) • Sleep management programme provided by MDT*. Interventions including but not exhaustive of: • Intervention workshops e.g.sleep hygiene education , cognitive procedures & relaxation • Signposting for additional help e.g. Clinical expertise required	• Referred for clinical sleep assessment at a clinical sleep research unit

Figure 6.1 A Hierarchy of Needs for the Measurement and Assessment of Sleep and Movement Behaviour in Elite Sport
**MDT - multidisciplinary team supporting athletes e.g. physiologist, psychologist, nutrition, medic, physiotherapist*

Outputs from a hierarchy of needs process ensures practitioners can identify and ultimately anticipate specific challenges to an athlete's fatigue management (e.g. competition stress) and consequently prepare a constructive response to an athlete's issue with fatigue management. It also helps to safeguard athletes in that practitioners can potentially identify the athletes who are vulnerable to poor sleep.

The above points fall under a comprehensive physiological support programme of delivery to a high-performance sport programme, but also rely on collaboration within the sports multidisciplinary support team. Such collaboration is assisted through the established 'EIS Sleep Management Decision Tree'. This was designed to aid practitioners in how to make suitable decisions in relation to fatigue management process for their athletes. Figure 6.2 illustrates the various decisions that need to be made and the subsequent level of support that such decisions dictate for the athletes' support team. This process can be adopted whether using a proactive or reactive approach to fatigue management. In essence, Figure 6.2 represents the 'what and how' of sleep assessment in athletic performance i.e. what is the potential problem and how can we find a solution to it.

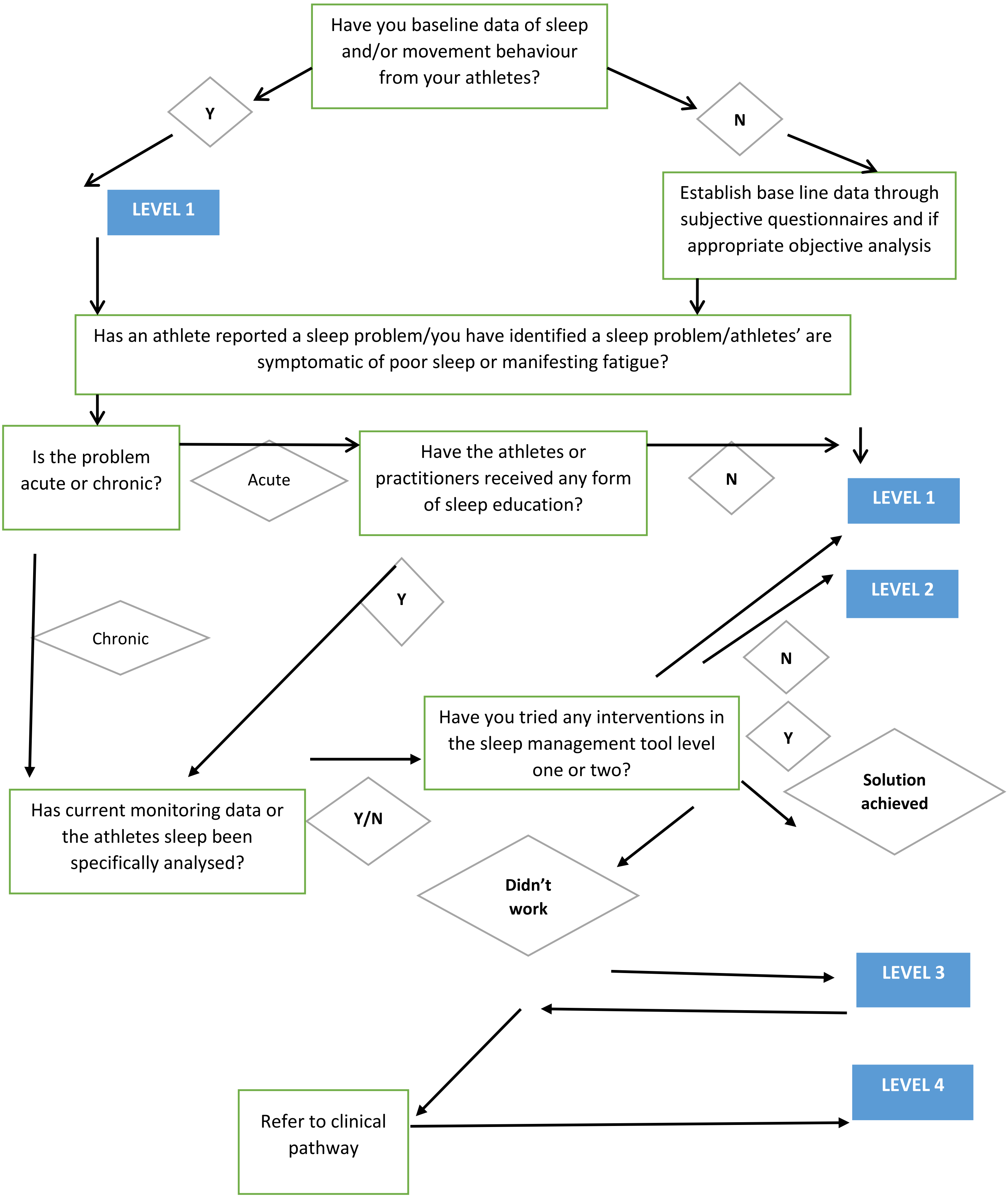


Figure 6.2 EIS Sleep Management Decision Tree

In 2016, parallel to these initiatives and the PhD development, I evolved fatigue management in a wider context and started to analyse more of the movement behaviour data. This, I presented at a National Conference (BASES 2016), where I was awarded the Routledge Recently Qualified Researcher Free Communication Presentation Award (2016). The project is outlined in more detail in the next section of this chapter.

6.5 Fatigue management projects

In order to exemplify the success and impact of projects within British Rowing and the consequent refinement of the fatigue management concept through my reflection of the rowing work, I shall now provide specific examples of projects involving different sports and their requirement for fatigue management input. It was the intention in the highlighted projects, to capture descriptive data on the sleep and movement behaviour characteristics of elite athletes and, thus, create a normative database for elite athletes' sleep characteristics (quality and quantity). Certainly, all the projects described below have provided Sports Science and Medicine support and coaching staff with previous unreported, unused and unrecognised quantitative and qualitative information on the sleep characteristics, quality and movement behaviour profiles of high performance athletes. In all cases presented, I was sensitive to not highlight sleep as a potential performance related issue: the aim being to have a positive view that establishing baseline measures of sleep quality and quantity and movement behaviour, which would be useful to a sports' elite performance programmes and could aid interventions should athletes report poor management of fatigue. I feel that this has been pioneering in its ability to provide novel information to elite sports programmes and was in accordance with Winter & Maughan (2009) who discussed that, in the context of sports science, there may be exceptional circumstances where retrospective analysis of data could provide pertinent information for a host of performance matters, e.g. talent identification, growth and development of athletes and training or other interventions. Through describing projects involving fatigue management I also intend to illustrate the *variety* of projects where fatigue management had an impact on 'What it Takes to Win' factors.

Two particular case studies are reported below in the sport of Rowing. These discreet studies were part of my usual work programme in my role as senior physiologist for British Rowing. Fatigue management projects fitted into my physiology role as it provided me with ownership of a technical area which I could lead on and disseminate knowledge and findings to the athletes, coaches and support staff. The case studies are identified as having impact to the British Rowing Team in terms of characterising sleep quality and quantity and movement behaviour in an elite rowing population. The first case study analyses the rowers' sleep and movement behaviour in two conditions; domestic (UK) and overseas (CAMP) training environments. The second case study provides objective data to support perceived differences in rowers' movement behaviour (downtime) when comparing two living locations. Following on from these projects are examples from other Sports involving fatigue management assessment and interventions.

6.5.1 British Rowing Project 1: A comparison of sleep and waking movement behaviour characteristics of an international Olympic rowing squad in domestic and overseas training environments.

I saw value in collecting more robust data on the rowers' sleep and movement behaviour variables following preliminary investigations of the British Rowing team's sleep and movement behaviour in 2010. I envisaged assessment of these variables could be developed into a more structured and proactive approach to characterising and developing normative values on elite rowers' sleep quality and quantity and movement behaviour.

The need identified by myself and key personnel within the British Rowing science and medical team for profiling a rowers' fatigue management through sleep and movement behaviour characteristics was varied. Typically, rowers were either referred by medical personnel as there was a clinical need to assess fatigue or there was a request from athletes or coaches for more information relating to their sleep or more global recovery due to training load management issues (implications for under-recovery, underperforming, training adherence). Sometimes athletes reported altitude related sleep problems: for example, the British Rowing men's senior team travel to altitude camps three times over a season. The highest altitude they train at is in Sierra Nevada at 2320 metres above sea level. It is on this camp where rowers had previously reported problems with sleep.

Whilst these needs were reactive, I identified that there was no objective data to verify perceptions of poor sleep and/or under-recovery and I wanted to proactively establish baseline data (at the start of a season) of sleep and movement behaviour and understand the current fatigue management state of rowers. This concept was led and innovated by me in the sense that no coach or athlete had asked the support staff any specific questions about sleep, but I fundamentally believed it was a concept worth exploring and gaining more information and data on, particularly within the elite rowing population.

A specific project in 2013 was approved by the Chief Coach (Senior Men) to assess sleep characteristics of British Rowing's open weight senior men's squad in the domestic environment (UK) and compare it to that of an overseas training environment at altitude (CAMP). This was significant on two counts. Firstly, there had never been a study investigating this within international rowing (or in a wider field). Secondly the senior men's Chief Coach was world renowned for successful rowing performances at Olympic level and to establish his acknowledgement of fatigue management as an important issue to investigate and report back to athletes and coaches, was a significant reflection of our practitioner-coach relationship.

The study involved 11 male competitive rowers (26.2 ±2.1 yr.; 97.9 ±5.7 kg). Sleep characteristics were assessed in both a domestic environment (UK) and at an overseas altitude training camp (CAMP), using non-dominant wrist actigraphy (Actiwatch AW2, Philips Healthcare, UK). Rowers wore an actiwatch for 21.4 ±1.12 consecutive nights segregated by 9.7 ±1.01 nights in UK and 11.7 ±0.65 nights in CAMP conditions. UK and CAMP sleep were recorded from day two of each scenario to allow for familiarisation with the watch, travel transition and time zone shift (GMT +1 hour). Sleep structure was assessed by discriminating; time to bed (hh:mm), time in bed (min), get up time (hh:mm), actual sleep time (min) and sleep latency (min). Sleep quality was determined as; sleep efficiency (%) (derived from Actiwatch software algorithm). Movement behaviour was assessed by the percentage time immobile and mobile during active periods (calculated from the accelerometer in the

Actiwatch). Definitions of sleep markers assessed are outlined in Chapter 5, Table 5.1. Mean values from the 21.4 ±1.1 consecutive nights of sleep data were used as the outcome measure for each of the sleep actigraphy variables. Analyses provided 95% confidence intervals for all comparisons. Table 6.2 displays the results for both conditions for the sleep and movement behaviour variables.

Table 6.2 Data of sleep and waking movement behaviour characteristics of an international Olympic rowing squad in domestic (UK) and overseas training (CAMP) environments

Sleep variable/ Condition	Time to bed (hh:mm)	Time in bed (min)	Get up time (hh:mm)	Actual sleep time (min)	Sleep latency (min)	Sleep efficiency (%)	Level of inactivity (Immobile) (%)	Level of activity (Mobile) (%)
Domestic (UK)	23:00 ±0.09	427.0 ± 73.1	06:20 ±0.04	362.7 ± 62.3 vs.	9.5 ± 12.2	80.4 ± 6.7	5.8 ± 4.38	94.2 ± 4.36
Oversees (CAMP)	23:20 ±0.02	428.2 ± 37.3	06:28 ±0.02	350.6 ± 37.8	18.8 ± 21.0*	76.3 ± 7.1*	6.6 ± 4.50	93.4 ± 4.50

*Statistically significant camp vs. UK (P = 0.00)

Results suggest sleep structure, as indicated by time to bed (hh:mm), time in bed (min), get up time (hh:mm) and actual sleep time (min) was similar between domestic (UK) and oversees (CAMP) environments and not different (P>0.05). This is with the exception of sleep latency (min) which displayed a significant difference with rowers taking less time to get to sleep in the domestic (UK) versus oversees (CAMP) condition (9.5 ± 12.2 vs. 18.8 ± 21.0 min) (P = 0.00). Similarly, objective measurements of sleep quality showed rowers having improved sleep efficiency in the domestic (UK) versus the oversees (CAMP) environment (80.4 ± 6.7 vs. 76.3 ± 7.1) (P = 0.00). This was probably due to the fact that in an oversees environment (CAMP) rowers share rooms, sleep in unfamiliar sleep systems (bed, pillow, mattress, bed linen etc.) and environments (e.g. altitude) and tend to experience a higher volume training programme than in their normal domestic environment. There were no differences in movement behaviour variables between the two environments, suggesting the nature of the rowing training day means rowers get the same opportunities to rest whether in domestic (UK) or oversees environments (CAMP).

The above data enabled me as a physiologist to evaluate the differences in sleep quality and quantity and movement behaviour between the two environments. Whilst most variables were not statistically different, the data provided valuable objective and previously unrecorded data on an elite rowing population in two different training programme conditions. Similarities in sleep structure were probably due to the strict training regime of the sport of rowing and were concurrent with previously recorded findings in rowers (although not as elite) (Leeder *et al.* 2012, Kolling, 2015). This study also allowed me to encourage and engage with greater multidisciplinary team working to proactively identify interventions for improved sleep hygiene, for example, planning specific pre-sleep strategies, and improved sleep systems (bed, pillow, mattress). Further, it helped me to work closely with the Chief Medical Officer and coaches to negate the culture of pharmacological interventions for improving sleep and improve alternative sleep hygiene practices (Appendix 4).

6.5.2 British Rowing Project 2: Living location in relation to a centralised training venue and associated movement behaviour

After project one, a further analysis was also conducted on rowers' fatigue management (sleep characteristics and movement behaviour) in relation to the distance lived from the rowers' home location to a centralised training base. Once again, I was working with 11 male competitive rowers (26.2 ±2.1yr.; 97.9 ±5.7 kg). Differences in sleep and movement behaviour characteristics were assessed using the criteria of a 30-mile radius cut off from the centralised training venue in Caversham, England. Athletes were placed into two groups; greater than 30 miles (>30 mile, n=5) or less than 30 miles (<30 mile, n=6) from the centralised training venue.

Sleep and movement behaviour characteristics were assessed in a domestic environment using non-dominant wrist actigraphy (Actiwatch AW2, Philips Healthcare, UK). Sleep was recorded from day two of each scenario to allow for familiarisation with the watch. Sleep structure was assessed by discriminating; time to bed (hh:mm), time in bed (min), get up time (hh:mm), actual sleep time (min) and sleep latency (min). Sleep quality was determined by sleep efficiency (%) (derived from Actiwatch software algorithm). Movement behaviour was assessed by the percentage time immobile and mobile during active periods (calculated from the accelerometer in the Actiwatch). Definitions of sleep markers assessed are outlined Chapter 5, Table 5.1. In this chapter, Table 6.3 displays the results for both conditions for the sleep and movement behaviour variables.

Mean values from the 9.7 (± 1.0) consecutive nights of sleep data were used as the outcome measure for each of the sleep actigraphy variables. Analyses provided 95% confidence intervals for all comparisons.

Table 6.3 Data of sleep and movement behaviour characteristics of for an international Olympic rowing squad discriminated by those living less than (<30 miles) and greater than 30 miles (>30 miles) from a centralised training venue.

Sleep variable/ Location	Time to bed (hh:mm)	Time in bed (min)	Get up time (hh:mm)	Sleep onset latency (min)	Sleep efficiency (%)	Actual sleep time (min)	Level of inactivity (Immobile) (%)	Level of activity (Mobile) (%)
<30 mile	23:09 ± 1:12	436.8 ± 69.6	6:17 ± 1:03	6.1 ± 9.8	80.0 ± 6.37	368.0 ± 58.6	7.3 ± 4.9	92.7 ± 4.9
>30 mile	22.47 ± 2:59	419.0 ± 73.3	6:26 ± 00:58	13.2 ± 13.7	81.0 ± 6.76	359.4 ± 65.1	3.8 ± 2.4*	96.1 ± 2.4*

*Statistically significant (*P* = 0.00)

In terms of sleep structure and quality**,** no significant differences (*P*=0.05) were observed in the sleep structure variables of time to bed (hh:mm), time in bed (min), get up time (hh:mm), actual sleep time (min) and sleep latency (min) in relation to living location. Objective sleep quality assessment of sleep efficiency (%) also displayed no significant differences (*P* = 0.05) in relation to living location. There was a trend for athletes living more than 30 miles away to be asleep for less time (actual sleep time) and to take longer to get to sleep (sleep onset latency) (Figure 6.3 and 6.4).

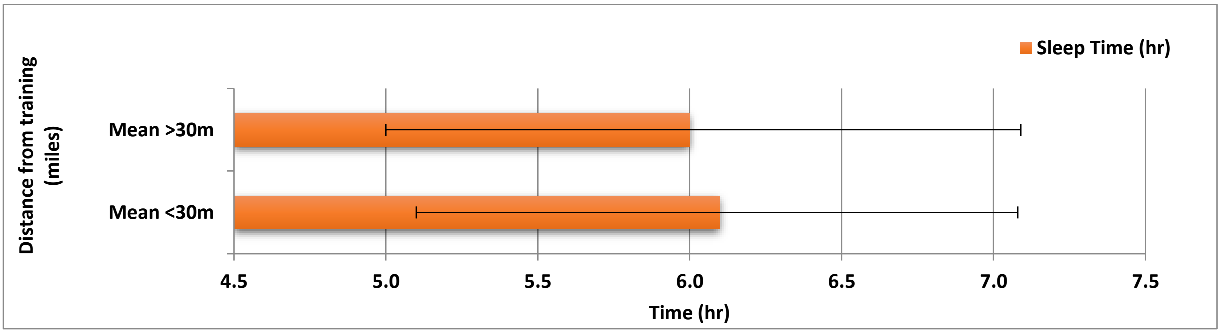


Figure 6.3 Total sleep time in relation to living location

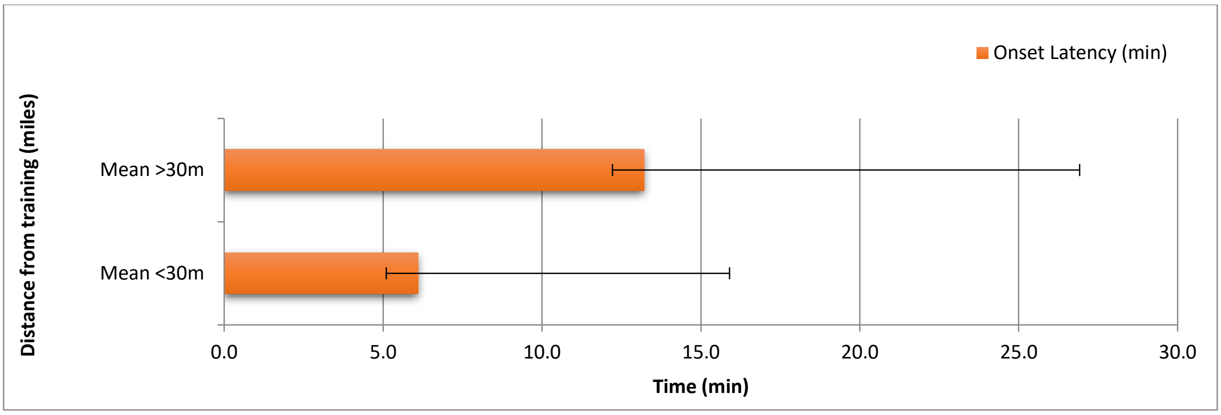


Figure 6.4 Sleep onset latency in relation to living location

Significant differences were observed in the waking movement behaviour variables. Rowers who lived more than 30 miles from the centralised training venue received significantly (*P*=0.00) less immobile time ('downtime') than those living within 30 miles (3.8 ±2.4 vs. 7.3 ±4.9 % respectively) and consequently more mobile time (96.1 ±2.4 vs. 92.7 ±4.9 %). This equated to those living more than 30 miles away having 41 minutes less immobile time over the 2-week assessment period than those who inhabited within 30 miles, who had 79 minutes of immobile time.

This discreet data analysis helped to highlight what, as support staff, we already suspected. It provided quantifiable evidence that rowers who lived further away from the centralised training venue (> 30 miles) experienced less immobile time (downtime) during waking hours than rowers living within 30 miles of the centralised training venue. A factor contributing to this is likely to be the greater time spent travelling to and from training. Needless to say, extrapolating less recovery opportunities (downtime) to a longer micro, meso or macrocycle would have a potential impact on what it takes to win factors for individual rowers e.g. through potential over training issues.

In terms of sleep structure and quality variables there were no statistical differences suggesting the rowing training regime heavily influences time to bed (hh:mm), time in bed (min), get up time (hh:mm), actual sleep time (min) and to a certain extent sleep latency (min), but movement behaviour during daytime activities are affected by athlete behaviour.

An additional success from this project was the impact and knowledge it provided to British Rowing, and the wider UK high performance industry. For example, the rowers' awareness of their sleep strategies (or lack of) improved as a result of the projects we conducted. The projects also highlighted the need for more actigraphy units to be available within the EIS to deploy for fatigue management assessment. Having more units meant a greater number of athletes could be assessed at any one time, making team sport or whole squad analysis of sleep and movement behaviour more favourable. Given the financial constraints of UK Sport and correspondingly, the EIS, the fact we received sizable funding (circa £10000) for the purchase of more actigraphy units for the 2016 Rio Olympic cycle, displayed the faith the system had in me providing education and support to practitioners and sports on fatigue management.

6.5.3 Additional projects

The British Rowing examples are just some of the projects completed with sleep and waking movement behaviour since 2010. The demand for projects beyond that from British Rowing have involved ad-hoc requests for advice on performance questions regarding slightly different applications relating to sleep and movement behaviour e.g. crossing of time zones. These projects were supervised by me and completed by the PhD student. They were justified in the sense that whilst the projects were relevant for the Rio 2016 Olympic cycle (2012-2016), they also had future implications for the Tokyo Olympic cycle (2016-2020) and therefore warranted investigation through the objective and subjective sleep and movement behaviour methods already described. The projects also served as an opportunity to gather preliminary data for the PhD research proposal and for the PhD student to gain experience in using sleep and movement behaviour resources and technologies. All the projects described benefited from reflection and refinement from the previously described rowing projects. In addition, they added to the developing database that I was establishing on athletic sleep and movement behaviour characteristics.

6.5.3.1 Project 3: Olympic preparations

A principle project to stem from my 2013 EIS National Conference forum on sleep and movement behaviour was with GB Canoeing. As part of my EIS technical lead role and sleep PhD supervisor, the sport's performance director asked me to advise on this project in order for the practitioners and coaches to achieve a greater understanding of the Brazil holding camp environment (prior to Rio 2016), know the challenges involved and be able to influence future strategies aimed at optimising performance during Games time. In short, the sport needed to know if athletes responded poorly to travel and the camp environment and could this be influenced by effective sleep strategies? If so, what were the 'at risk' areas of their preparation? Fatigue management through assessment of sleep and athlete movement behaviour were identified as one of these 'at risk' areas.

Therefore, I needed to compare UK and training CAMP based sleep variables. I involved my 'sleep PhD' student in the project in order to develop their analytical skills with sleep technology devices and presentation of sleep variables in objective formats. Further, this not only fitted into my work programme as supervisor to the sleep PhD, but also helped to enhance my growing knowledge of sleep and movement behaviour and establishing different means of disseminating data and knowledge to athletes and coaches.

The squad planned to travel to Brazil on a reconnaissance trip in 2014 and, using actigraphy procedures described in Chapter 5, they wanted to understand several factors including travel management (on flight care), volume load on days 1-3 post arrival, session number, recovery intervals between sessions and strategic rest days post return to the UK. They also wanted to understand the ratio of on water conditioning versus conditioning and individual athlete adaptability to travel fatigue and time zone shift. The project timescale was the largest analysis time scale we had completed to date using actigraphy. It involved 40 days of analysis of 12 canoe sprint athletes including;

1. A 12-day training camp in the United Kingdom
2. 1 long haul flight to Brazil with an ultimate time zone change (February, Brazil = 4 hours-GMT)
3. A 21-day training camp in Belo Horizonte (the identified venue for the Team GB holding camp at the Rio 1016 Olympics)
4. A 10-day window of analysis in the return home phase of the training programme

Particular challenges to the project were battery time of the actiwatches and ensuring that the athletes kept them on for the full duration of the project. This was overcome by setting a longer epoch (1 minute) to record data in the actiwatches. This scarified obtaining fragmentation index (restlessness) data but the principle sleep and movement behaviour variables could still be obtained. As a consequence of this project, conclusions were drawn in the form of performance impact statements from the sport in question which are outlined below:

1. Individual, group and coach feedback sessions facilitated conversations around impact of recovery on overall athlete training adaptation. For example, athletes were using downtime far too frivolously and therefore not adhering to good recovery practices (e.g. shopping for hours on foot). Feedback sessions allowed them to see the impact of poor downtime choices via their actograms and make the necessary changes in their behaviour ahead of the Olympic competition phase.

2. 'At risk' athletes derived from the sleep data generated, by discriminating key sleep variables e.g. sleep efficiency and total sleep time, were highlighted and provided with follow up 1:1's focusing on sleep hygiene and optimising stress/recovery balance.

3. Data from the actograms was used by the coaches and physical preparation practitioners to aid prevention in post competition/training illness strategies e.g. planning appropriate downtime.

4. Following a training camp debrief, information captured from the actiwatches was used to inform future trips to Brazil and update the GB Canoe Performance Service scope document e.g. long haul flights selection and timings were altered and a greater emphasis was placed on individual athletes' travel management.

5. Data captured from the actiwatches was used to show a wider EIS impact in partnership with the British Olympic Association (BOA) around Games services and optimising performance. This was particularly pertinent given the novel nature of the data captured and interventions employed.

This project also highlighted the agile nature of fatigue management assessment in that it can be moulded to any scenario requiring analysis. The 'package' offered by support personnel was not limited to specific scenarios for analysis, e.g. a laboratory environment, which allowed ecological validity to the project. It also displayed flexibility in the manner of project management and being able to adapt according to the needs of the sport.

6.5.3.2 Project 4: Subjective reporting of athlete's sleep

As part of my role as supervisor to the 'sleep PhD' was advising on what could be impactful findings from the PhD to the UK high performance sport system. Particularly impactful was a novel project conducted by my PhD student involved designing a pioneering self-reporting questionnaire of over 400 British elite multi-sport athletes (183 female) aged 26.5 ± 0.7 yr. of which 78% were Olympic/Paralympic; Commonwealth Games or senior World Championship level. The idea being that at the start of the PhD we identified that we did not know the extent of the UK athletic population's knowledge about sleep. I helped the PhD student establish that this could be completed relatively simply via an online questionnaire to all available athletes in the UK high performance system. I advised the PhD student the best way to achieve 'buy in' by all sports concerned and consequently allow us to ask their athletes' questions relating to sleep and athletic performance. The project was presented at the recent 'Sleep 2017' conference[8] and was a direct objective in the PhD student's development plan.

We categorised sports into five distinct areas; team, endurance, technical, combat and power. Global sleep quality was evaluated using the previously described Pittsburgh sleep quality (PSQI) (Chapter 5). For the PSQI poor sleeper thresholds of >5 and >8 were adopted and the questionnaire was augmented with questions addressing non-restorative sleep, excessive day-time fatigue, and how athletes' sleep has changed since reaching an elite level of performance. Within-sport comparisons were made between gender, age groups (<23, 23-27 and >27 yr.) and ability (Paralympic vs. Olympic). We used a Friedman's test to assess differences between sport types and also relative risk (RR) for scoring >5 and >8 on PSQI for sport type, gender and ability were calculated. A significance level of $p<0.05$ was employed (Gupta *et al.* 2016). Our results displayed the median global PSQI score as 5 (interquartile

[8] The Annual Meeting of the Associated Professional Sleep Societies LLC (APSS), a joint venture of the American Academy of Sleep Medicine (AASM) and the Sleep Research Society (SRS).

range=3) with a range from 1-17. The prevalence of participants scoring >5 was 45%, and those scoring >8 was 16%. PSQI scores between sports can be seen in Table 6.4.

Table 6.4 Relative risk between sport types, ability, gender and age for scoring >5 and >8 on PSQI (Gupta *et al.*, 2016)

	PSQI >5				PSQI >8			
Risk factors	**Freq (%)**	**Risk ratio**	**95% CI**	X^2	**Freq (%)**	**Risk ratio**	**95% CI**	X^2
Sport-types								
Team	44	0.98	0.63 -1.49	0.02	11	0.62	0.30 - 1.08	3.07
Endurance	45	1.02	0.75 -1.39	0.01	14	0.80	0.48 -1.35	0.72
Technical	52	1.36	0.90 -2.04	2.14	33[a]	2.58	1.76 -4.10	19.6
Combat	49	1.18	0.76 to 1.59	0.24	15	0.93	0.40 to 2.14	0.03
Power	37	0.81	0.58 to 1.16	1.42	12	0.70	0.36 to 1.45	0.98
Demographic								
Paralympic	51	1.31	1.00 to 1.56	3.77	27[b]	2.57	1.66 to 3.99	18.90
Female	44	0.97	0.78 to 1.21	0.07	18	1.14	0.74 to 1.77	0.36
>27 y	49	1.20	0.90 to1.44	1.59	25[c]	2.08	1.35 to 3.21	11.24

Note: [a] sig. diff. to all other sports combined ($p<0.05$); [b] sig diff to Olympic athletes; [c] sig. diff to athletes <27 y; Freq, frequency; PSQI, Pittsburgh Sleep Quality Index.

We found that combat sport athletes reported more awakenings in the month prior to assessment compared to team sport and power athletes ($P<0.05$). Technical sport athletes reported the lowest sleep efficiency compared to endurance and combat sport athletes ($P<0.05$). From the entire sample, 15% stated that their sleep had deteriorated and 62% stated their sleep had remained unchanged since reaching an elite level of performance. Global PSQI scores for between sports-types and between sports can be seen in Figure 6.5 and 6.6 (Gupta *et al.* 2016).

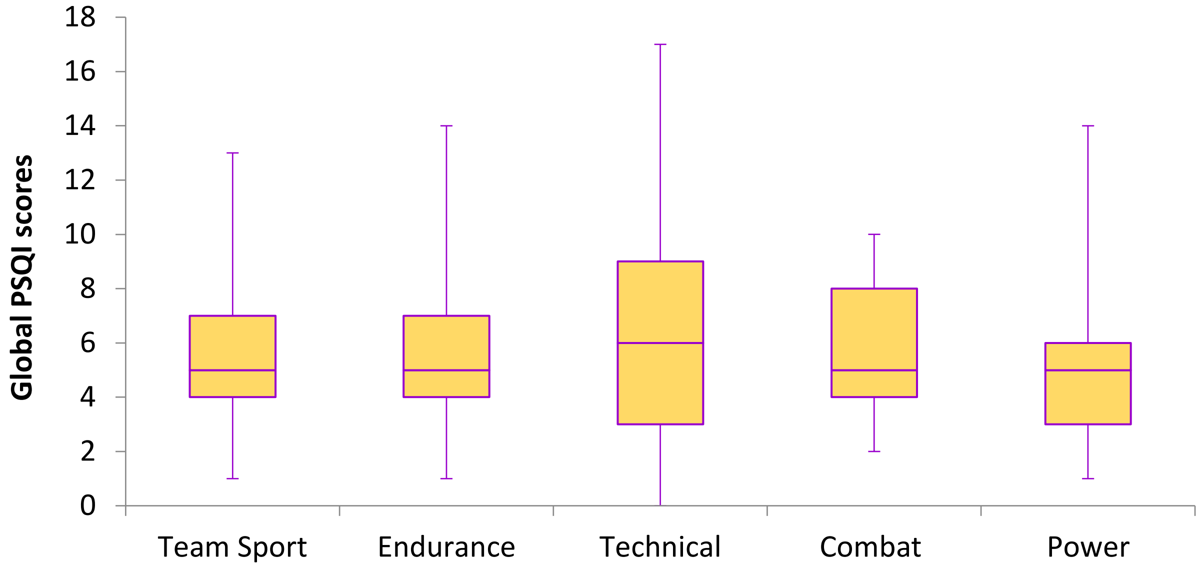


Figure 6.5 Box-whisker plots for PSQI global scores between sports-types (Gupta *et al.*, 2016)

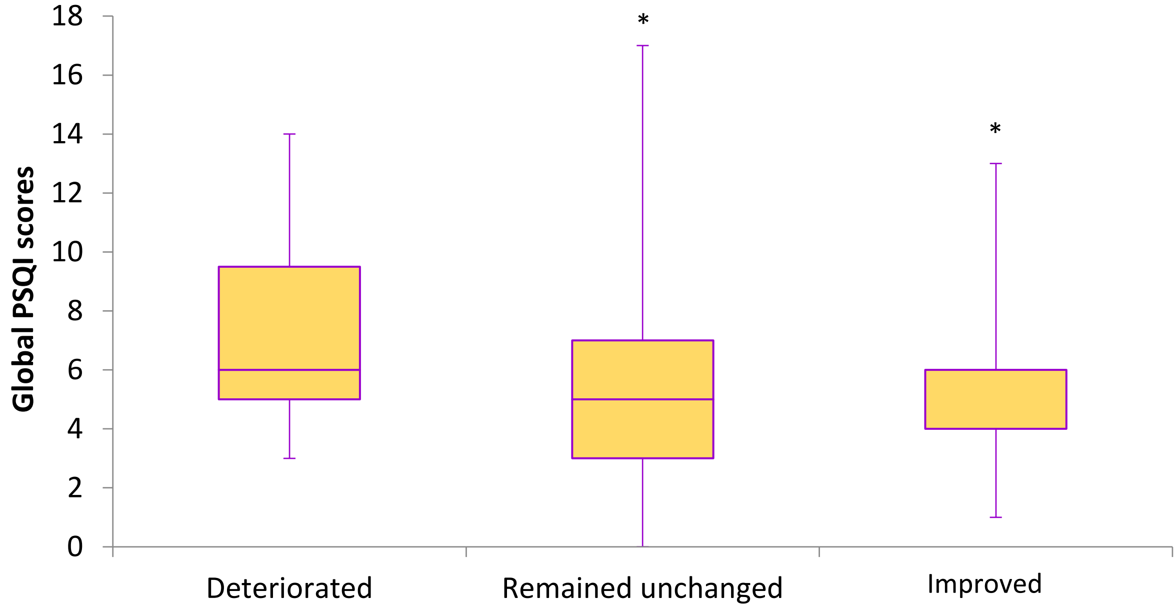


Figure 6.6 Box whisker plots for PSQI global scores between sports, *significantly different to "deteriorated" (Gupta *et al.*, 2016)

Our conclusions from this extensive questionnaire were that elite sport is associated with high levels of sleep disturbance, with differences being observed between different sports. We reported that it is likely that the lower levels of athleticism required in technical sports allow elite performance in these activities to be less influenced by degraded sleep quality (Gupta *et* *al.,* 2016). However, it is worth noting that a large proportion of athletes stated their sleep had remained unchanged since they had attained elite level status in their sport, suggesting that good sleep quality may not necessarily be a prerequisite for participating in elite sport, nor does it necessarily degrade it (Gupta *et al.* 2016). Finally, it was suggested that Paralympic sports and sports which select for an older demographic (e.g. technical sports) are at a greater risk of experiencing poor sleep quality, which has implications for targeted sleep management (Gupta *et al.* 2016).

6.6 Impact and learnings: methods of optimal practice to measure and analyse sleep and movement behaviour

The projects described in this chapter have impacted on the development of fatigue management programmes throughout the UK high-performance sport industry. British sports have actively engaged in projects relating to fatigue management to help best prepare them for international competition e.g. Olympic and Paralympic Games, 2016 and 2020, Cycling World Championships, 2017 and British Gymnastics World Championships 2017. Practitioners within these sports now regularly utilise technologies to capture data on athletes' objective and subjective sleep. I take immense pride in the knowledge that my initial work with British Rowing and drive to disseminate information, knowledge and robust scientific practices has spearheaded such a change in practice throughout the UK sports science industry.

Since the inception in 2010 of using rudimentary objective sleep measurement tools within my work programme, the knowledge and capability to capture, analyse and provide interventions for the enhancement of athlete sleep and movement behaviour has evolved through multiple means. Most notable has been the strategic direction that I have taken the topic, namely; determining methods for optimal practice for sleep screening (measurement and analysis), technical knowledge growth and dissemination, up-skilling of practitioners as to how to technically measure sleep and movement behaviour and the supervision of the PhD in athletic sleep. Examples have been highlighted throughout the thesis, such as Sports projects, supervising research and leading and presenting forums and workshops. Significantly from such work, several enhancements to fatigue management practices, including good sleep education applications, for sports have emerged. I shall now elaborate on some of these practices.

6.6.1 Normative data

As a consequence of Sports' projects involving objective assessment of sleep and movement behaviour characteristics, I have been able to collate a database of normative values not only for a generic athletic population but for the various categories within such a population. As an example of good professional practice, I now have normative data on athletic sleep and associated movement behaviour for gender, sport-type (i.e. combat, endurance and team) and different sleep environments (e.g. altitude versus sea level, centralised training versus home environment). It is hoped that this database of elite athletes' sleep and movement behaviour can be further scrutinised and information disseminated in a useful manner to the wider Sports Science and Medicine arena. It is also valuable information which can be used as part of a strategy moving forwards and such a strategy is outlined further in this chapter.

6.6.2 Optimal Practice

In considering the optimal practice for solving fatigue management problems it is good to recognise the complexity of the environment one is working within. Where practitioners can adopt 'best practice' methods are in more process driven tasks relating to, for example, the methodologies to assess sleep and movement behaviour. Here a quality assured process is necessary for confident assessment of fatigue management.

Where quality assurance is present but the problem or scenario requires some flexibility and acceptance of being complicated or complex in its nature, practitioners should aim to provide 'good practice'. Within a complex environment, such as an elite training programme, practitioners observe analysis methods for understanding the problem, sense, probe and seek out signs and symptoms of an intervention's success en route to a proposed solution, whilst ensuring flexibility pervades on the path to the solution. An example of complexity is in the delivery of interventions to enhance fatigue management of athletes. Here, understanding the problem (e.g. poor performance or poor sleep and/or downtime) is complicated given the myriad of factors contributing to successful sporting performance or a 'what it takes to win model' (described in Chapter 1). Under these circumstances practitioners need to consider the analysis methods for understanding the problem, and the means for sensing or probing complex issues. With this considered approach practitioners require a level of expertise in fatigue management which they can use to safely navigate their way through to providing solutions to coaches and athletes using intuition and experience.

The kind of optimal practice approach that could be adopted in deciding appropriate courses of intervention and management with athletic sleep was illustrated earlier in this chapter in the EIS Sleep Management Decision Tree (Figure 6.2). By its nature fatigue management is complex and chaotic and requires a good level of communication from all parties involved. A good fatigue management programme will involve the aspects outlined in Figure 6.2, e.g. intervention workshops incorporating sleep hygiene education (Appendix 4), cognitive procedures & relaxation, and that the intervention(s) may not always be able to be delivered by a physiologist. In these circumstances, the physiology practitioner should be acutely aware of professional boundaries ahead of delivering any intervention. Further, good professional practice would be to return to athletes tested and assess how they are doing after the intervention.

Therefore, where practitioners recognise fatigue management issues may be having an impact on a what it takes to win model, they can employ an optimal practice approach. That is, some circumstances will require 'best practice' to be employed i.e. protocol for using actiwatches. However more complex scenarios will require a more flexible, 'good practice' approach to deliver solutions. Striving for best practice in scenarios involving high performance sport settings will rarely result in it being achieved, given the complex nature of elite sporting programmes and the aforementioned multivariable what it takes to win models.

In terms of what is good practice for providing a fatigue management service in elite sport and as a consequence of my experiences, I recommend practitioners screen their athletes and undertake a programme of sleep quality and movement behaviour measurement through both objective and subjective means. Sports' performance programmes need to consider that the most effective and optimal practice at the beginning of any fatigue management programme would be to capture baseline data on normal sleep and movement behaviour practices (ideally at the start of a season) in some form i.e. objective, subjective or both. However current practices dictate that this step is often discounted in the haste of attempting to establish information for a specific performance issue e.g. sleep responses in a competition phase. In addition, I propose that once baseline data has been collated, further analysis should be conducted when athletes report a change in sleep, or identified 'at risk' athletes need reassessment following intervention(s) or there is a direct performance question relating to sleep and movement behaviour e.g. competition at altitude. Using the simplicity of the actigraphy technology can aid this process as it turns a rudimentary data capture process into a powerful tool for performance gain interventions.

6.6.3 Subjective Questionnaires

As we learnt in Chapter 5, the gold standard objective sleep measurement tool is PSG, however this is impractical as a field measure primarily because it is complicated to administer with elite athletes due to the nature of it methodology. Therefore, the field based method of Actigraphy, also described in Chapter 5, provides a valid and reliable measurement tool for assessment of athletic sleep. This, alongside subjective self-report questionnaires, provides a comprehensive methodology for data capture, assessment and intervention of both subjective and objective sleep and associated movement behaviour. This is a progressive step as it has become clear over recent years that there was a lack of validated subjective analysis of sleep alongside the objective assessments that were being conducted within sports. It is proposed that the best method of subjective assessment of sleep is through completion of five key self-assessment questionnaires, namely; 1) Pittsburgh Sleep Quality Index, 2) Epworth sleepiness scale, 3) Dysfunctional beliefs about sleep, 4) Ford Insomnia Response to Stress and 5) the Morningness/Eveningness Questionnaire. Together, these provide a comprehensive assessment of an athletes sleep as they encapsulate sleep practices, quality and self-perception of sleep. However, I suggest that, where completion of all five of these questionnaires would be ideal practice, there is the acceptance that this is not always possible and a prioritisation of a few, at the discretion of the Sports' science and medical team, would suffice if practitioners were trying to expedite data collection. A description of the five questionnaires is provided below.

Pittsburgh Sleep Quality Index (PSQI)

A well established and validated self-assessment questionnaire (Buysse *et al.*, 1988) which provides a useful insight into an individual's subjective sleep quality and discriminates between good and poor sleepers. Sleep quality is a complex phenomenon that involves several dimensions, each of which is covered by the PSQI and include subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medications, and daytime dysfunction (Buysse *et al.*, 1988). Individuals answer 19 questions relating to their sleep over the past month. These answers create seven component scores covering the dimensions listed above. The sum of the scores for the seven components yields a global score of which generally >5 indicates poor sleep quality. Where sleep issues have been identified through the PSQI, interventions to improve athlete sleep can involve expertise from a multitude of Sports Science and Medicine disciplines

Epworth Sleepiness Scale (ESS) (Johns, 1990)

This relates to sleep debt and is a useful assessment of daytime function. It stems from respiratory medicine where it is used predominantly to assess daytime function as a result of sleep loss relating to obstructive sleep apnoea. Coupled with objective data this can be a powerful tool in the assessment of an individual's sleep quality.

Dysfunctional Beliefs About Sleep (DBAS)

This is a 28 statement self-assessment questionnaire relating to perceptions of sleep. It evaluates sleep-related beliefs, querying respondents' expectations and attitudes regarding the causes, consequences, and potential treatments of sleep issues. The DBAS questionnaire can be used to target athletes' education about sleep i.e. what it is or is not and help dispel myths or an individual's beliefs relating to their sleep. Essentially it can help treat subjective symptoms of poor sleep and be particularly valuable in the formation of cognitive approaches to treatment; for example, a cognitive reconstruction of an individual's beliefs about sleep (Shahid *et al.*, 2012).

Ford Insomnia Response to Stress (FIRST)

A diagnostic self-assessment questionnaire using nine items which measure the propensity for disturbed sleep under stress and ultimately can aid in identifying individuals predisposed to insomnia. Therefore, it is a standardised measure of individual vulnerability to stress-induced sleep disturbance, i.e. insomnia (Drake *et al.*, 2008). The instrument tests the likelihood that an individual will get sleep disturbances following various stressful events, for example in sport this could involve training load increases, selection phases or competition phase.

Morningness/Eveningness Questionnaire (MEQ)

This relates to an individual's chronotype. It is a 19-point self-assessment questionnaire developed by Horne & Osberg (1976), with its main aim being to measure whether a person's circadian rhythm produces peak alertness in the morning, in the evening, or in between. In considering subjective assessment of sleep, it is worth noting that through the PhD I was supervising, we discovered that whilst the PSQI was an incredibly useful and valid self-assessment tool for athlete sleep, it is in fact the Ford Insomnia Response to Stress (FIRST) questionnaire which provides the most effective data when used in screening procedures by sport science practitioners to identify resilient (but also vulnerable) sleepers among elite athlete squads (Gupta *et al*., 2017). This is primarily because it identifies 'reactive sleepers', i.e. those who are sensitive to interventions to improve sleep quality. Such information can be used to inform targeted sleep management programmes, where hyperarousal is a mediating factor for poor sleep quality, but also to identify individuals who are able to extend sleep through day-time napping (Gupta *et al*., 2017). This discovery was pioneering in that for future fatigue management assessment, it changes the subjective screening of sleep from traditional PSQI assessment to bespoke analysis of sleep reactivity. It therefore gives Sports Science and Medicine personnel and coaches an awareness of those individual athletes who are more likely to be sensitive to sleep disturbances. Importantly, this does not discriminate elite athletes as the sole population experiencing sleep reactivity. As mentioned in Chapter 4, the propensity for sleep reactivity can manifest in any number of scenarios (e.g. ballet dancers/students), but if an individual with high sleep reactivity finds themselves in an elite sporting environment then, potentially, they may not be as robust with their sleep and cope less well in the elite sporting environment as opposed to their contemporaries.

Another point to consider in providing optimal practice assessment of fatigue management is the timing of the 'sleep', i.e. pre-competition sleep, pre and post training sleep or sleep extension practices, e.g. napping. In addition, the athletes' environment should also be taken into account, i.e. whether athletes are in their normal training environment, away on training camps or at competition (Erlacher, 2011, Silva *et al.*, 2013, Juliff *et al.*, 2015). Where possible, baseline assessment of sleep and associated movement behaviour should be determined before being assessed under different circumstances. Whilst this may be difficult to achieve given the complexity of world class training programmes, it can be planned in effectively with good communication between coaching and science and medicine staff. This is something I managed to achieve with British Rowing through having worked with the Sport for a number of years before the fatigue management projects began. This ensured I had the trust and respect of peers and coaches. Finally, any assessment to sleep and movement behaviour should be performed over a 2 week period to allow for consistent data capture and it is important to recognise that it may be a while before you analyse and use the data, so ensure that you have set expectations of the athletes and coaches initially.

6.7 Sleep hygiene

In providing support to elite athletes and practitioners around the concept of fatigue management, of significance has been the concept of 'sleep hygiene' as a primary area where athletes can improve to enhance their sleep. This concept encompasses all environmental and behavioural aspects of pre-sleep and involves tactics to improve fatigue management. Typically, athletes are unaware of simple processes they can implement to improve sleep hygiene and ultimately improve their subjective perception and objective quality of sleep. From my experience, and if aiming for optimal practice, sleep hygiene should be incorporated into any fatigue management programme with elite athletes (Lastella *et al.*, 2014, Juliff *et al.*, 2015). For example, encouraging athletes to adopt practices to placate sleep have been useful educational tools that have had a lasting and deep impact on athletes' sleep latency (time to get to sleep), duration and quality. Examples of methods to improve sleep hygiene include sleep behaviour (all aspects in relation to your approach to sleep e.g. strategy, routine, hygiene, nutrition and system). An example of a sleep hygiene education sheet can be found in Figure 6.7.

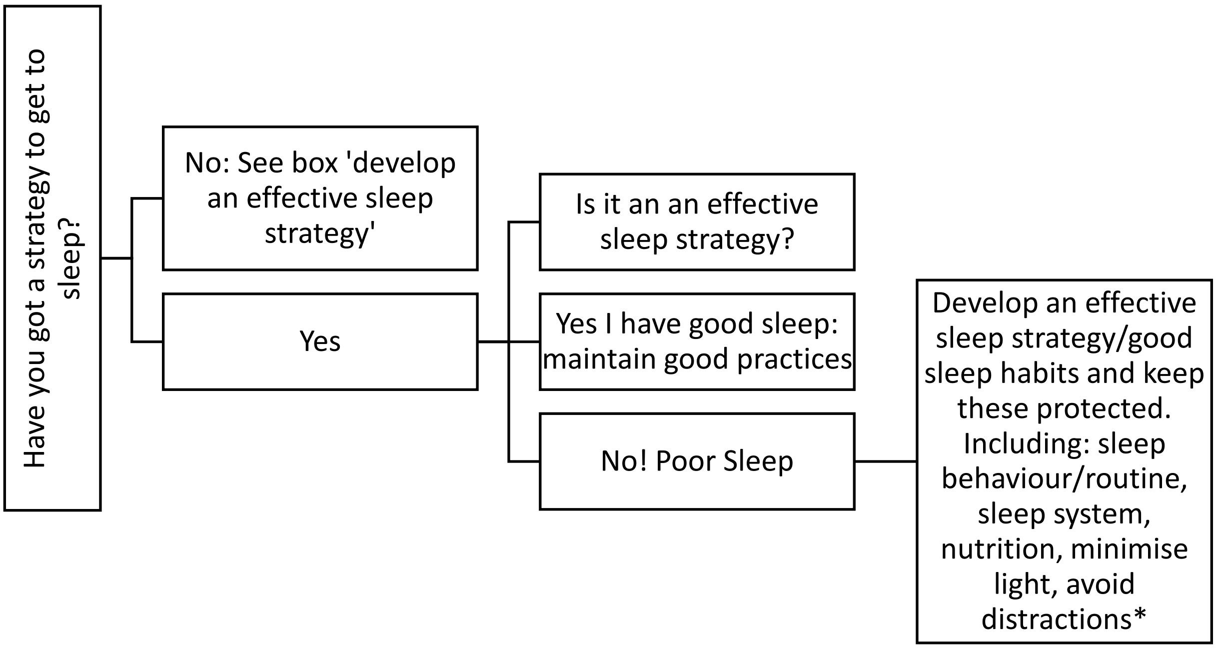


Figure 6.7 An example flow diagram for good sleep hygiene.
**refer to more detailed examples in Appendix 4*

6.8 Impact

Through using a combination of the described self-assessment tools, effective fatigue management programmes can be assessed for their ability to decrease any dysfunctional beliefs around sleep and as a consequence increase sleep efficiency. This is exemplified through a short questionnaire asked of elite athletes as part of a studies related to the sleep PhD I co-supervised. Here, over 40 elite athletes were asked to record the impact of an intervention (several sleep management education sessions) on their sleep during a) normal training and b) a competition phase. Figures 6.8 and 6.9 display the results from both cohorts. Overall, athletes felt the sleep interventions provided had firstly, a positive impact on their wellbeing and or performance(s) and secondly, they used the information during training and competition. Additional feedback was that they would recommend the sleep interventions to other athletes, felt the information from the interventions was relevant and therefore felt equipped to deal with sleep disturbances as a result of the interventions and would use the information again in the future. Setting expectations also has implications for the success and impact of the projects too.

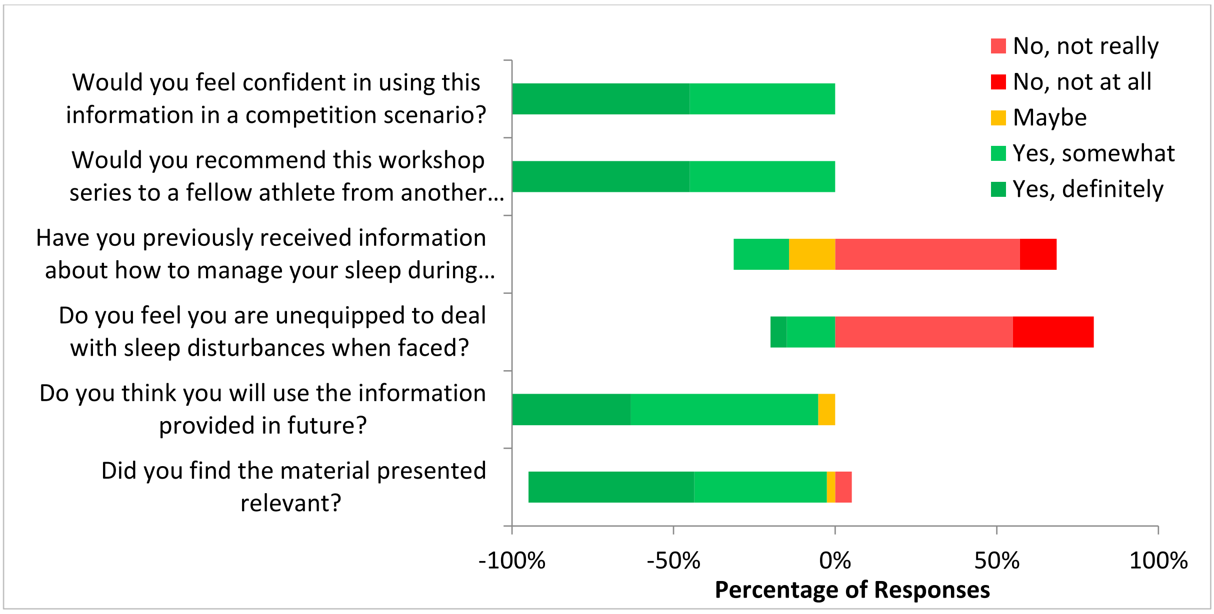


Figure 6.8 The impact of interventions for sleep education on elite athletes (training)

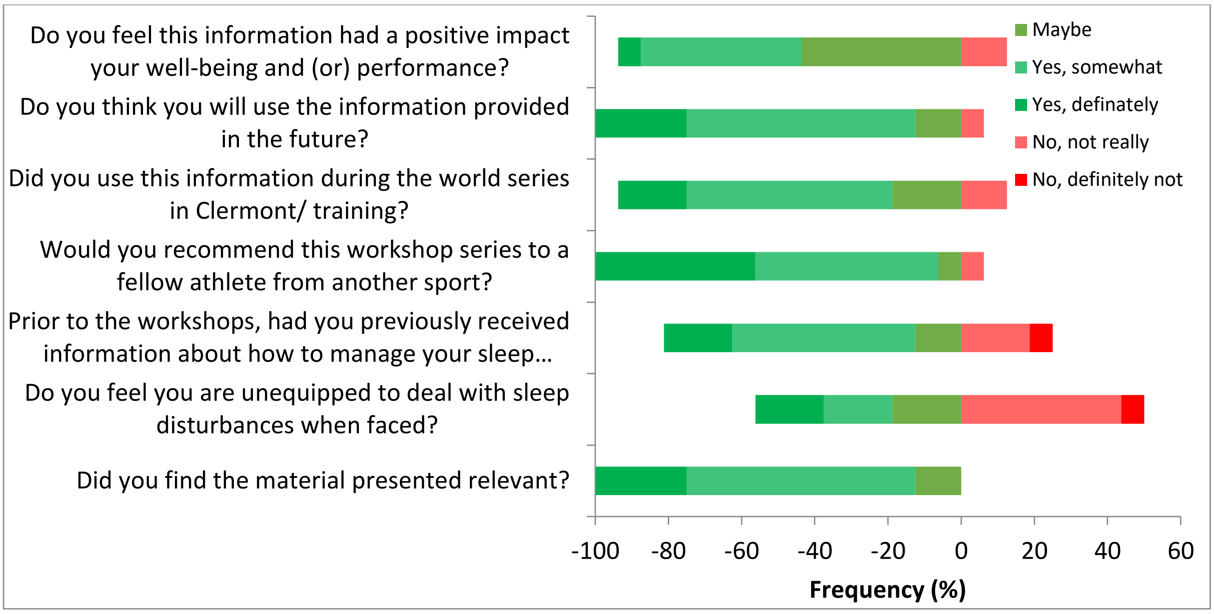


Figure 6.9 The impact of interventions for sleep education on elite athletes (competition)

Alongside educating athletes on good fatigue management strategies, providing objective data of their sleep quality and characteristics to pacify fears of poor sleep has also been particularly impactful. A detailed bespoke analysis of results has helped this process, for example, providing athletes with their standard deviation (SD) of bed-time across a two-week period (provides an indication of the level of consistency in athlete bed-times) and their standard deviation get-up-times across a two-week period (provides an indication of the consistency of athlete get-up-times).

Additional to this has been the ability to illustrate through actograms (demonstrated in Chapter 3) and display objective data to athletes regarding their movement behaviour. This is in an attempt to enhance the previous suggestions in Chapter 4 of poor sleep management practices existing within the sport industry. What I endeavoured to do here was enhance existing practices and introduce new ones, to ensure education regarding fatigue management was a structured process in high performance sport, with information provided as to the most appropriate methods athletes can use to encourage an optimal fatigue management strategy whether it be through modifications to their approaches to sleep or movement behaviour.

In terms of impact, the manner in which projects are delivered to Sports and individual athletes has evolved. Now it is much more holistic and multidisciplinary in approach. However, any project still requires a lead and it is in the domain of fatigue management where physiologists can take such a lead. For reasons already outlined, in Chapters 3, 4 and 6; sleep being a psycho-physiological process and the overall 'load' on an athlete being of primary interest to the physiologist, means they are ideally suited to leading projects relating to fatigue management. This would, without question, be in close collaboration with other necessary members of the multidisciplinary support team around a coach and athlete and with respect to professional boundaries.

It's important to consider that not all sports employ a physiologist so, on occasion, those sports would need an appropriate designated practitioner who can have direct collaborations with physiologists who hold fatigue management expertise within the high-performance sport system. This is akin to other areas in Sports Science and Medicine where debate exists as to ownership of an 'area'. For example, where core stability and low motor control are considered, there is ambiguity between physiotherapists and strength and conditioning coaches as to who takes responsibility for the assessment and intervention for improvement of athletes' core stability issues. Similarly, in nutrition and strength and conditioning there can be confusion as to who leads on an intervention to increase lean muscle mass as both disciplines contribute significantly to muscle hypertrophy. Equally worthy disciplines to contribute to the intervention but there remains a lack of transparency about who would necessarily lead on the project to improve the issue.

Qualitative feedback (presented in Chapter 7) from those involved in the evolution of the concept of fatigue management in high performance sport, has meant that I can confidently present the fact that introducing the concept has ultimately been a success. Similarly, within the industry of sleep management, the concept of sleep and sport has had an impact. Recent innovative advances in smart phone applications for management of sleep have been developed. Specifically, the smart phone application, 'Sleepful', a self-help programme for insomnia (www.sleepful.me), has been developed through a series of publicly funded research studies and clinical trials in the UK and is led by Professor Morgan (co-supervisor to the EIS Sleep PhD). Future plans are to evolve this to a specific application for sporting populations and is an example of how this and the EIS sleep PhD have created ideas and creativity in the area of athletic sleep.

6.9 Sleep and athletic performance strategy

As a result of the work described in this chapter and throughout the thesis, I wrote the fatigue management strategy for the EIS (Tokyo cycle 2017-2021) (Appendix 4). Key to this process was the recruitment of the PhD student as this post increased opportunities for developing detailed knowledge and augmented scope for assessment of athletic sleep. From my work with elite athletes and the sleep PhD research, it has become abundantly clear that there are more questions, beyond the scope of the current sleep PhD, that need to be answered to further our knowledge on athletic sleep. Part of the strategy suggested harnessing existing information into a collective format and using for knowledge gain within the industry. One example of this is to create a normative database for athletic sleep, analyse differences (e.g. endurance versus team sport, altitude versus sea level training camp, gender differences) and provide pragmatic solutions. Therefore, a primary aim of the EIS sleep strategy was to provide solutions focused on investigating further questions on the topic of fatigue management and to future proof the current knowledge so it could be harnessed and utilised for performance gains in future Olympic and Paralympic cycles.

In summary, providing optimal practices for fatigue management in elite athletes, ensures the innovative approaches used to impact on performance using sleep assessment follow approved rigorous scientific technologies and techniques. This ensures ‘sound science’ is in place to thoroughly investigate and answer discreet performance questions regarding fatigue management. In line with this, it is imperative that when assessing sleep and associated movement behaviour (or any other impact factor on performance), that you ensure you understand what you are collecting and why.

> P4 ‘’Yes, understanding why you're collecting the information, and how it's going to have a positive impact on their decision-making, is crucial’’.

6.10 Summary

In this chapter I have provided a summary of my work evolving fatigue management, through sleep and movement behaviour assessment, in the high-performance sport industry. My intention was to present how an initial idea from a discreet project that I delivered pre-London Olympics 2012, has developed into an impactful part of routine practitioner service delivery. The outlined projects, normative data capture on athlete sleep and movement behaviour variables and knowledge disseminating platforms have helped to pioneer recognition of fatigue management to be part of the assessment of factors impacting on athletic performance and ultimately 'What it Takes to Win'.

Through directing formal education of multidisciplinary practitioners on how to characterise, monitor and assess sleep and associated movement behaviour, I have been able to educate, system wide, why fatigue management is important and crucially, what is absent in our knowledge. These projects and initiatives have all involved high-level skills in critical and innovative thinking, generation of ideas and explanation of scientific principles to high performance coaches, athletes and support staff. All have necessitated strong influencing skills aimed at harnessing practitioner expertise and professionalism around fatigue management. Equally necessary has been an ability to be able to competently critically discuss contemporary issues, such as fatigue management and evaluate how such technical and non-technical practices to enhance management of athletic fatigue can impact and influence sporting performance. The process has also required an ability to be solution focused and proactive in seeking to collaborate with colleagues to identify performance problems with the aim of producing intra or multidisciplinary solutions.

In summary, the discreet and innovative projects presented in this chapter have provided examples as to how fatigue management can influence the successful attainment and delivery of performance determinants. This has allowed coaches, athletes and support staff to have a clear insight into how fatigue management potentially impacts on 'What it Takes to Win' in a given sport.

Chapter 7 General Conclusions and Future Recommendations

7.1 General conclusions

This chapter will provide final conclusions drawn against the thesis aims and objectives (outlined in the thesis overview and provided below as a reminder), and a summary of the process of introducing the concept of fatigue management to the high-performance industry. Importantly, it will also elaborate on some future recommendations for research, applied practice and an overall strategy to progress fatigue management in high performance sport.

Thesis objectives:

1. To ascertain the growth of Sports Science over the last 20 years and how fatigue management has emerged as part of the industry development

2. To assess current literature relating to sleep and movement behaviour and athletic performance

3. To determine why physiologists should take responsibility for sleep and athletic performance measurement and assessment

4. To provide examples of fatigue management projects in high performance sport and methods of optimal practice for assessment of fatigue management

5. To make recommendations for future research and applied practice in relation to fatigue management of elite athletes

6. To assess the impact of evolving the concept of fatigue management to the UK high performance sport industry

I have demonstrated throughout this thesis how the topic of fatigue management has evolved in the UK high-performance sport industry. I have provided examples of how some of the UK's high-performance sport programmes have engaged with fatigue management as an 'impact factor' in their 'What it Takes to Win' (WITTW) models, with the ultimate aim of providing intelligence for training and performance gains. To add additional insight, I have collated qualitative evidence of the impact of evolving the concept of fatigue management. A summation of the narratives obtained from the qualitative piece I conducted (described in

Chapter 2) are provided throughout this chapter in Tables 7.1-7.4 and 7.6-7.8. These verbatim quotes provide context to my work in fatigue management within the UK high performance sport network and also illustrate the novelty and evolution of the concept of fatigue management.

7.1.2 Reflections on the process; success, impact and challenges of evolving the fatigue management concept

7.1.2.2 Success and Impact

The process of recognising the disparity between traditional academic sleep research and applied sport and engaging the UK high-performance sport industry to recognise fatigue management as a worthwhile contributing factor to performance, has been a complex and change orientated issue. This issue has required a step approach involving establishing relationships with academics, engaging them with applied sports science work flows, assessment of current literature and identification of common links between research and applied settings. Connecting the UK high performance sport industry in an evolving concept, has therefore, involved research into what has been done before and holding a critically reflective orientation in my positionality.

During the process of championing the new concept of fatigue management (through research, developing and leading new ideas and dissemination of knowledge), I achieved financial investment for new equipment, training and research through an EIS funded PhD. Funding the sleep PhD at the start of a new Olympic and Paralympic cycle (2012-2016), where the opportunities for pioneering ideas were encouraged[9], helped to support the importance of investigating the sleep and athletic performance relationship. This was particularly pertinent in combination with the fact that there was, traditionally, a general lack of awareness by practitioners as to how and why they should consider fatigue management and assess sleep and associated movement behaviour.

Further to that of others, I myself have had to critically reflect on the area in applied practice and articulate to a varied audience (i.e. practitioners, athletes, coaches and performance directors), why fatigue management should be considered as an impact factor on 'what it takes to win' on the international sporting stage. I feel that this has been of particular success, in the context that, there has been a collective uplift in engagement of fatigue management across the UK high performance sport industry. In short, the concept has felt pioneering to me personally and to the UK high performance sport sector, since its initial inception (2010) and through to observing delivery of live practices of fatigue management projects in the current 2020 Tokyo Olympic cycle. It is a project I have been committed to, embraced and relished doing.

My personal reflections of my fatigue management projects' impact, coupled with the insights displayed from my qualitative research and my dissemination of academically and professionally valid knowledge to peers within the industry, has allowed for acceptance of fatigue management as a novel concept within the UK high performance sport industry. A 'different way of doing things' was recognised throughout the 2016 Rio Olympic/Paralympic

[9] The EIS Physiology PhD model 2012/16 was a new concept in collaboration with EIS Laboratory Technician roles. It worked well to provide research opportunities for those working in posts indirectly linked to Sports.

cycle (2012-2016) and was demonstrated to have a direct effect and impact on sports' performance programmes. This has been evidenced by the work presented in this thesis (Chapters 4, 6 and 7 in particular) and through anecdotal evidence and personal interactions with peers in the UK high performance sport industry. Equally, working hard to focus on achieving 'athlete buy in' to any fatigue management projects has also been of value to the success of any project involving analysis and measurement of sleep and/or movement behaviour. Quotes relating to athlete buy in are presented in Table 7.1.

Table 7.1 Verbatim quotes relating to athlete buy in to sleep measurement and analysis

P3 ''I think athletes firstly buy into it [fatigue management], because sleep's one of those things that not many people are that aware of, and they have a grasp of how they slept when they wake up in the morning, and they know when they can't fall asleep at night or they have a particularly bad night's sleep because they're waking up, but to give an athlete an opportunity to say we can actually look at your sleep in a bit more depth by simply either whatever at all it is, I think that's something that's quite powerful, and athletes buy into quite readily, because it is very simple, it's not invasive''.
P3 ''Yes, so I think that's when this [fatigue management] can be quite impactful. I think just raising that level of awareness, that in itself is probably the biggest thing you can do, and dispelling myths, [about sleep] I suppose. Those two things combined are very powerful. So when athletes take part in these kind of monitoring exercises, they buy into it quickly, like I said before, because it [sleep] is easy to do, and they're fascinated by it [sleep] because everyone is fascinated by their sleep, and because at the moment, there seems to be this emphasis upon sleep and performance, and how you need to sleep well to perform well. They seem to buy into it [sleep] even more so…''
P2 ''If you've explained it [sleep and movement behaviour assessment] to them, and they understand why we're doing it [sleep and movement behaviour assessment], and it's not like we do it [sleep and movement behaviour assessment] every day of the year, because you know we picked certain times when we were having problems or issues, and had a look all the way round the baseline so that we knew what they were like generally. So I think on the whole, I think the rowers have become quite accepting of it [sleep and movement behaviour assessment] as something that we look at, and if they're struggling to understand what's happening, of course if it [sleep and movement behaviour assessment] can help, then they're open to it''.

Facilitating the powerful source of contextual insights from 20 years' experience in the high-performance sport industry (outlined in Chapter 1) was that of the pre-2012

Olympic/Paralympic Games pilot work (described in Chapter 6), along with accumulated academically and professionally valid knowledge over the London, Rio and Tokyo Olympic/Paralympic cycles (2008-2016). Through the Professional Doctorate I was then able to consolidate such experiences and knowledge through thoughts behind new concepts, theories and critiques. As such I have been able to present to a range of audiences and across platforms to the UK high-performance sport industry's coaches, athletes and support staff, the importance of considering fatigue management and athletic performance in their performance planning processes (WITTW models). This was part of a purposeful approach to showcase the impact fatigue management can have on WITTW models and enhance industry understanding of the concept of fatigue management.

Certainly, the science of sleep and the importance of good sleep for athletes is becoming more commonplace in athletic preparation strategies. Olympic sports such as Gymnastics, Sprint Canoe, Cycling, Rugby 7's and Rowing now consider fatigue management as part of their preparation for major competition and some sports have commendably employed the use of bespoke commercial 'sleep systems' to enhance athletes' sleep whilst away from home (Littlehales, 2012). However, what is generally lacking is an evaluation of such practices. For example, where a sport uses fatigue management techniques to capture data on athletic sleep, rarely is there a follow up to assess the success of a sport wide intervention. Evaluation of a successful intervention may occur on an individual athlete basis, but there needs to be more of a focus on reflections of fatigue management interventions for a whole squad's benefit e.g. British Gymnastics 2016 World Championships Travel Strategy.

Nonetheless, engagement in optimal fatigue management practices has had a direct effect and impact on UK current applied Sports Science and Medicine practice by opening dialogue between coaches, athletes and support staff, identifying potential fatigue management issues in individual athlete's and developing fatigue management education programmes relating to different aspects of training and performance (e.g. training versus competition). Table 7.2 includes quotes from interviewees regarding the evolution and engagement of the concept within the UK high performance sport industry.

Table 7.2 Verbatim quotes from interviewees regarding the evolution and engagement of the concept of fatigue management within the UK high performance sport industry.

P5 ''…..we've reached a point in the [sleep] literature where there's a possibility that improved quality sleep can deliver a more integrated performance, but there's also a downside, so we're also aware that if there was such a thing as monitoring losses, that disturbed sleep, which we're increasingly realising is a constant risk in high performance sport, that disturbed sleep might actually detract from marginal gains made in other areas, and for me, one of the really interesting aspects of the research that you and myself and L have been conducting is the focus it's brought on the downside of the demands of elite performance on sleep''.
P3 ''Yes, the fact that the Institution are saying, "OK, this area of sleep deserves a structured programme of research". OK, there's obviously one something that is good enough to research, and we've kind of seen in the last three years that it's [fatigue management] gone outside of the PhD into something that's Institution-wide, how it's [fatigue management] addressed. So I think that was probably there the tipping point, I think. As soon as the PhD was introduced, it kind of tipped over the edge, and now people are kind of jumping on a [fatigue management] little bit more''.
P5 ''….we [PhD student and supervisors] designed a one-day [sleep] workshop which we felt delivered most of our messages to date, and reflected the kind of world view of sleep in sport. But this is where we developed this idea of we do not big it [fatigue management] up, we proportionately deliver messages about sleep, and we focus on solutions rather than problematising it [fatigue management]. And it worked, it [workshops] really worked well. It worked well for me for two reasons. One of them is because three of us worked well in delivering the messages, but the interactions that then developed between trainers, between sports physicians, between practitioners and ourselves guaranteed a feedback of information that we used to modify our messages, and to develop other messages''.

By encouraging fatigue management to become an established part of an athlete's assessment profile and through the reporting of some projects involving investigations into sleep, associated movement behaviour and athletic performance, the impact of introducing this concept becomes apparent. Overall, introducing the concept of fatigue management, through sleep and movement behaviour measurement and analysis, has I believe, advanced the understanding of fatigue management in athletic performance and therefore been a success.

Critical factors to that success have been as follows. Firstly, and vital to the process, was proactively increasing athlete, coach and support staff awareness of fatigue management; what it is and how to manage it. Consecutive to this was an ability to contextualise information for relevant audiences and gain adherence and 'buy-in' from the scientific, medical, coaching and athletic populations analysed.

Secondly, using actigraphy to objectively demonstrate to athletes their sleep and movement behaviour profiles and by describing fatigue management in such a manner, evaded causing alarm, but increased pragmatic decisions made by athletes and coaches in relation to their fatigue management.

Further, and critical to the success of my strategy to introduce fatigue management to the UK high performance sport system, has been a long-term goal of establishing the EIS site at Bisham Abbey as a Centre of Excellence for fatigue management knowledge. This centre would include all aspects relating to sleep and associated movement behaviour and athletic performance e.g. sleep extension, circadian rhythm disruption and training versus competition. Through observing impact, exponential increases in project requests involving fatigue management and outputs for dissemination of knowledge, it is clear that this has been achieved. Most recent evidence being advising Team GB/Paralympics GB on their sleep and travel plans for the Tokyo 2020 Olympic and Paralympic Games. For example, the EIS Research and Innovation Team's consultancy work with Sports regarding their Tokyo travel strategies. Additional kudos to this process has been the collaboration with Professor Morgan at the Loughborough University Clinical Sleep Research Unit and funding from the EIS itself to further disseminate knowledge throughout the system. Principle means for this being through ad hoc consultancy with priority athletes and the aforementioned workshops to Sports regarding sleep and athletic performance (Chapter 6).

Table 7.3 outlines some of the quotes from interviewees regarding the impact and success of evolving the concept of fatigue management in the UK high performance sport industry.

Table 7.3 Interviewee responses regarding impact and success of evolving fatigue management as a concept

P1 ''I think there's an awareness now [of fatigue management], and it's, I think it will, when we [practitioners] reflect back after, I think it will be that thing of the [Olympic] cycle. You know when you have something, and everyone goes, "Actually, that [fatigue management] was probably the biggest learning curve in a lot of sport''. P4 ''…we [practitioners] looked at some sleep profiles ten days before we got on a long-haul flight going to Brazil, and we saw a gender-specific issue, again with a very small subject group, but on the back of that I've heard a few other conversations of other sports when I've chatted to them about it [fatigue management], and it kind of makes sense. So that information has led to us changing flight times before the pre- [Olympic] Games camp''. P4 ''Yes, without a doubt. It [sleep] unlocks a lot of conversations with coaches around really specifically looking at the work to rest ratios on day one to three when you land in an environment, and yes, without that information, it [fatigue management] would have been just a conversation, without necessarily any weighting towards it [fatigue management]''. P3 ''Yes, when it [a sleep project] is managed carefully, and athletes' expectations are set beforehand, and they adhere to what they're meant to be doing properly, and then they give you the information back, and that information is interpreted, and the message is presented, a kind of not overemphasised, and everything's done kind of that way, it [fatigue management] works really well''

P4 ‘’I think I would probably view this work flow [sleep] as pretty high up in terms of value add to sports, so sports invest in the institute from a practitioner perspective, but also expect to get auxiliary benefits by investing in an institute, and I see this work flow particularly as something that has a start and an ending to it, so it doesn't elongate and blur those, and I think it's [fatigue management] been a quite nice little package that can be delivered across a number of sports, and has been done, so without necessarily requiring too much follow up on the back of the information there, and it [fatigue management] can have relatively quick impact’’.

P4 ‘’Impact is primarily around reassurance. With some of the athletes, it's making them feel that they're normal. There's been a couple of specific examples where lifestyle has impacted on sleep, but understanding what that looked like would not have been achieved without looking at the sleep before or after it.’’

P3 ‘’So then, they [athletes] basically just wore sleep watches, and that was it. Now they [athletes] get an online survey which has a questionnaire side to it, they would wear the sleep watches, and the emphasis is not entirely on the sleep watches. Now it's kind of this is a part of it [fatigue management], not the entire assessment package. There's also this side to it, and when it all comes back, it's presented in a much more holistic way that will probably involve different practitioners and different disciplines, as opposed to just me going in and talking about sleep’’.

P2 ‘’I think the [sleep] analysis allows us [Sports Science and Medicine support team], to have some discussions with the rowers which we perhaps could not have before. It introduces the concept of how do you prepare to sleep, why have you got such variable bedtimes, what are you doing in your life outside of rowing, which they may not have felt that they wanted to talk to us about, or we may not have felt we had the right to go and enquire about, but having data which showed maybe they were variable, or they were going to bed extremely late and not getting much sleep, then we had an introduction to discuss such things with them. But it also raised for us the possibility that there were other things going on that they might not be dealing with, like restless sleep, and were there family issues or issues in their lives which actually they weren't in control of. And so that raised us [Sports Science and Medicine support team], again, the opportunity to have a discussion, and ask them to volunteer things to us which they may not have felt they could talk about before’’.

7.1.2.3 Challenges and Adversities

Principle challenges identified by athletes were primarily centred around a perceived lack of privacy; athletes needed to feel practitioners were not over scrutinising them. As coaches and practitioners already assess such large portions of an athlete’s overall training regime, their sleep is often the last area of their lives that is not assessed and measured. Therefore, in my work with athletes, I had to be careful to educate athletes, via group workshops ahead of individual actigraphy assessments, as to why I was gathering information on their fatigue management and how the data could be used to aid training and performance.

Delivering one of the initial education workshops to British Rowing was, in part, a success as well as a challenge, as the Chief Coach, who I was working with, planned the workshops directly into the training programme. This was a personal achievement in my relationship with the Chief Coach who rarely scheduled anything else into their training programmes. This sent a message to the squad in question that the Chief Coach believed the fatigue management concept to be important and therefore they should follow suit.

Further challenges were the fact that athletes may attempt to skew data by seeking to falsify the actigraphy assessment. Careful explanation of the reasons why fatigue management was being assessed and expectation management would negate this from happening.

In line with this was the 'so what' question. Meaning coaches would ask, "we all sleep so why do we need to assess it"? Another uncertainty was whether coaches and athletes would engage with the concept given that there was no direct quantifiable link to performance enhancement? Here, concise explanations and practice-based evidence helped to engage relevant parties.

The process also involved an element of risk in that I did not know if other Sports Science and Medicine disciplines would 'buy in' to the concept. I also had to ensure that the concept of fatigue management was not 'over-emphasised'. Presentation of message was therefore key to the success of any fatigue management project. Instinct and intuition provided a large part of my motivation to be proactive and drive the change in practice as I knew the consequences of including fatigue management in athlete assessment would be of benefit to performance programmes.

However, we were a product of our own success and whilst the UK high performance sport system bought into sleep and movement behaviour as worthy impact factors on performance and worth monitoring, the demand often exceeded the resources available to deliver such support. The 2016 ‘sleep roadshows’ helped initially in terms of educating practitioners on what sleep was and the various options available to them to capture data on sleep and movement behaviour in line with their Sport(s) ‘What it Takes to Win’ (WITTW) models. However, this did not prevent Sports contacting myself or my PhD student for direct help in delivering sleep projects. The demand for this became too much at times and was not a good use of our time as some Sports hadn’t appropriately aligned sleep queries to their WITTW models, nor did it develop our technical knowledge of Sleep as a lot of the work was repetitive in nature. This unfortunately led to some adversities in terms of relationships with Sports and their practitioners having to understand their WITTW models better to make more informed decisions as to the priority areas in their Sports performance programmes. Further, at times, too many people became involved in projects as there was, in some cases, duplicity and confusion in leadership and guidance of practitioner. Following the Rio 2016 Olympic Games, the restructure of the United Kingdom’s Governing Bodies of Sport and the EIS’s high performance support management stream, helped to clarify some of this confusion.

The difficulties in resource demands coincided with matters of expectation management. For example, I had to consider the fact that practitioners receiving information on the sleep and downtime practices of their athletes, potentially may fail to contextualise information gathered against training plans and this could potentially affect any athlete and coach engagement. With this in mind, I had to be succinct and transparent about how practitioners (me) were going to analyse and use the data, particularly as there was the potential for a large amount of both subjective and objective data generated.

The demographic of the athlete population in certain sports also presented some challenges. For example, in one sport where a fatigue management project was delivered as a result of the workshops presented (outlined in Chapter 6), the athletes were from a challenging socio-economic background. Consequently, good sleep and downtime routines had perhaps been either been non-existent in their development as a young athlete or at the very least were not seen as a priority by coaching staff.

A greater, though typical challenge to elite athlete sleep, arises from international competition, and consequent travel fatigue and circadian desynchrony. This was particularly pertinent to the Rio 2016 and Tokyo 2020 Olympic cycles. Therefore, the challenge was to educate practitioners as to the benefits of gaining baseline data in the normal training environment ahead of initiating projects relating to potential issues involving long haul travel.

In line with long haul travel data collection, a particular adversity in relation to the Rio 2016 Olympic Games and sleep and movement behaviour projects, was a project I discussed with Team GB in relation to support staff and assessment of their fatigue management practices during 'Games Time'. This idea stemmed from my conversations, in the lead into the Rio 2016 Olympic Games, with members of the Team GB (and Paralympic GB) leadership teams and key Sport and EIS Sports Science and Medicine personnel. Given the success of the sleep projects with some Sports, people in leadership positions for Team GB had rightly questioned whether we should collect data on Team GB support staff during this crucial phase of the Olympic cycle. The aim being this would provide intelligence on the sleep and downtime practices of support staff during ‘Games Time’, highlight any individuals with sleep issues and help in the preparation of future Team GB support staff in terms of optimal working performance and their overall health and wellbeing during this critical phase. The project gained some momentum in that I scoped out the logistics of providing resources to be able to collect the relevant data for such a project (e.g. actiwatches, online questionnaires, staff availability for analysis and reporting). However, the timing of the project was deemed to be too close to the start of the Rio 2016 Olympic Games and was therefore postponed, with recognition it would provide valuable information if such a project was launched in the future. I therefore suggested that instead, the EIS and Team GB run a pilot project with the upcoming Winter Olympics (PyeongChang 2018) and/or the 2018 Commonwealth Games (Gold Coast 2018), as both events involved eastward long haul travel and could provide valuable intelligence ahead of the Tokyo 2020 Olympic Games. This idea failed to gather momentum as I subsequently left the EIS and have been on maternity leave 2017/18 and, so far as I am aware, no one else took responsibility for it within either organisation.

Table 7.4 represents some of the interviewees’ perceptions of the challenges and adversities faced with the evolution of the fatigue management concept.

Table 7.4 Interviewees' perceptions of the challenges faced with the evolution of the fatigue management concept.

P1 ''I think, for me, my own kind of, if they [athletes] feel like they're being watched, so you're going to know where I am and what I'm doing, and also, I think, my concern was that they'd [athletes] make me want to see the data I wanted to see, rather than it [sleep and movement behaviour assessment] actually just being a natural process of just do what you normally do, it that they would actually try and, and I think they did for the first couple of days, and then, because we had it [actigraphy] on for three weeks, you can't sustain that because it's not your normal''.
P2 ''challenges were around the fact that they [athletes] already feel that rowing controls their lives, and they need to exist''.
P3 ''Yes, it [sleep analysis] could be like disadvantageous, in the sense that it's non-invasive, in the sense it's [actigraphy] easy to wear, and you just put a watch on and you go to sleep, but at the same time you're monitoring a part of their [athletes] lives that they may consider as quite private, and some athletes I've worked with are quite sensitive about this. Sometimes they [athletes' just take it [actiwatch] off, because they're uncomfortable about their sleep being monitored, and sometimes it's [sleep and movement behaviour assessment] doing the complete opposite in some cases to what you want it to do. So as soon as you slap a sleep watch on someone, their sleep becomes poor, because they know they're kind of being watched through this little watch on their wrists. So that's a downside to it'' [sleep and movement behaviour assessment].
P3 ''The biggest challenge, again is something I've only really learned in the last six months, is kind of over-emphasising the importance of it [fatigue management].
P4 ''we [practitioners] create a monster, and we haven't got the capacity to be able to analyse and interpret the information or contextualise it, so that would be the main challenge, and you isolate the very people that you're trying to bring with you''.

7.2 Future recommendations

Whilst the process of evolving the novel concept of fatigue management within the UK high-performance sport industry can be described as successful, there are further developments that can only serve to enhance the support and knowledge within the overall high-performance sport system, with the aim of enriching 'What it Takes to Win' models. This section will focus on future recommendations, categorised into either research or applied practice, that I believe will make a difference to fatigue management practices in high performance sport. Ahead of this I shall provide a generic overview of how and what to consider when planning a fatigue management project. Moving forward, this overview can be supported through using, for example, myself as a consultant in fatigue management practices to ensure practitioners are planning its assessment appropriately.

7.2.1 Fatigue Management Monitoring Overview

Ahead of making future recommendations I feel its relevant to provide a brief, generic overview of how and what physiologists (or other practitioners) should do in their desire to monitor the fatigue management of their athletes. This is in conjunction with the aforementioned EIS Decision Tree and Hierarchy of Needs (Chapter 6). Table 7.5 provides a generic overview of the fatigue management process for practitioners.

Table 7.5 A generic overview of the fatigue management process for practitioners.

Stage	Activity
1.	Outline the 'What it Takes to Win' factors for 'x' sport and identify a WITTW model which all performance programme staff align to
2.	Decide on the specific performance question and how Fatigue Management (F.M.) relates to it (e.g. sleep and movement behaviour's impact on the ability to deliver 'x' determinant of performance)
	If the issue is F.M. itself, then consider what the actual issue is and how to confirm this e.g. is it poor sleep quality or quantity, inadequate sleep hygiene, multiple nocturnal awakenings, poor sleep latency etc. or is it athlete downtime being mismanaged (movement behaviour)?
3.	Ascertain if F.M. has been addressed at all within the performance programme
4.	Educate the multidisciplinary team and coaches on what F.M. is and how and why it may impact on the determined WITTW factors
5.	Decide on which athletes to assess for F.M. (proactively or reactively) and the level of F.M. detail you wish to capture data on i.e. subject, objective data or both
6.	Decide on the most appropriate time in the training programme to capture data, including when to capture baseline values ahead of any other variable e.g. sleep at sea level vs. altitude
7.	Educate athletes on how and why F.M. is to be assessed
8.	Expectation Management: explain timeframes, commitments involved from athletes, support staff and coaching
9.	Capture data (in whatever form) over previously agreed time frames e.g. subjective questionnaires take the least amount of time (often single use) and can easily be repeated over a macro or mesocycle. Actigraphy provides objective data but should span a minimum of 2 weeks for adequate data capture (for methodology refer to Chapter 5). For a thorough assessment of sleep quantity and quality, and movement behaviour, using both subjective and objective means expect to capture data for a minimum of 2 weeks for baseline values.
10.	Analyse, review, interpret and feedback data to relevant parties. Include referral to specialist support outside of your boundaries e.g. physiology refer to medicine if poor sleep is a clinical issue
11.	Evaluate and review the impact of the F.M. project and future directions for it

7.2.2 Recommendations for research

Generally, knowledge in the literature about sleep, and associated movement behaviour, is good but how we apply that knowledge within the high-performance sport system, I consider to be less than ideal still, particularly when working with high performing athletes. Table 7.6 summarises some of the interviewees' perceptions of the Sports Science literature and sleep.

Table 7.6 Verbatim quotes from interviewees regarding sleep and Sports Science literature

P3 ‘’So I suppose a little bit ahead of its [sleep assessment] time, in a sense. Like a lot of people know generally a lot about nutrition and aspects of physiology, whereas the sleep, because the science of sleep is still very much in its infancy, they're still only starting to discover certain neuro-transmitters that kind of turn the sleep system on and off. They've only just discovered it in the last twenty years…’’.   P5 ‘’The interest from sports science in high performance exercise is probably, if you looked at it historically, it's bi-modal. It peaked around the late 1980's, then died off again, and then it's beginning to rise towards a peak now.’’ It’s only in the early 2000’s that we start to see an interest in actual sports performance, and sleep as an input, but it's kind of low grade. I think we have to wait until about 2012 when SM published this paper, demonstrating, no suggesting, that actually increasing amounts of sleep will increase accuracy and speed in elite performers, oh, and that's interesting’’   P5 ‘’So the [sleep] literature exploded during that period, there's lots of, if you were to search now on athletes' sleep, you'll find a lot of that literature, and it'll tell you very little about training cycle and performance, so it'll tell you very little about athletes, but it'll tell you a great deal about what we do not know about sleep’’.   P5 ‘’….it was pretty clear from my cursory view of the literature that sleep within sports science was neglected, so that there was a gain to be achieved, not just by scientifically linking certain parameters of sleep with actual performance. There was a gain to be achieved simply by formally introducing sleep science into sports science in a way that allowed sleep science to grow in this area, so that if we could foster interest in sleep science, then we cannot only gain immediately, but we could leave a legacy, and there may be something we'd develop from this’’.

Whilst fatigue management for enhancement of athletic performance is a relatively new concept for applied research and practitioner support, focusing on the topic both within the high-performance sport industry and in the wider academic arena, means studies will be more proactive in researching the appropriate questions, (related to WITTW), regarding the relationship between athletic performance, sleep characteristics, quality and associated movement behaviour.

As discussed throughout the thesis, generically, in the performance sport arena, sleep studies have focused on loose associations with recovery. What we do know is that a link between critical sleep factors, cognitive processes and metabolic function is evident (Samuels 2008). In generic terms optimising athletic training and performance recovery is essential to restore and allow adaptation. Sleep is the primary, and associated movement behaviour, the secondary opportunity, for restorative process to take place for elite athletes. Also, as reported in Chapter 4, research in elite athletes has shown that, in practical terms, athletes have poorer markers of sleep quality than age and sex matched controls (Leeder *et al.* 2012). Moving forward, specific identification of the performance questions in WITTW models relating to fatigue management need to be addressed with objectives planned and outcomes captured. This would require a robust implementation regime for fatigue management and I have outlined my suggestions for this later in this chapter.

Specifically, areas that practitioners could future investigate as precipitating factors for sleep disturbance in elite athletes and provide them with some understanding and holistic solutions could be; sleep extension practices (e.g. napping,) time zone shifts, chronobiology of athletes (larks vs. owls), training schedules, skill acquisition and pre-competition cognitive arousal. Further, observations into 'sleep reactivity' should also be considered, i.e. if you are predisposed to react with sleep issues under stress then this can potentially manifest if you are an elite athlete in periods of physical or mental stress, or both. Refer to Chapters 3 and 5 for further detail about this. More specificity in fatigue management investigations would form part of a strategic multidisciplinary approach, with particular sleep management strategies such as cognitive-behavioural techniques, being routinely practised within applied Sports Science and Medicine. These areas would also coincide with factors affecting performance in any WITTW model.

Specificity in measuring and analysing sleep, and associated movement behaviour, in research and applied sport settings, will be of impact as, until recently, most athletes' sleep observations were based on subjective accounts with little objective data reported (Leeder *et al.*, 2012, Sargent *et al.*, 2014). In support, through the qualitative research I conducted by interviewing key stakeholders involved in some of the projects outlined in this thesis, 100% of interviewees felt that introducing the concept of fatigue management had had a positive impact in, for example, increasing awareness of sleep and movement behaviour, improved practitioner delivery to athletes and athlete behaviour change around recovery.

7.2.3 Recommendations for applied practice

Alongside improving the applied research regarding fatigue management, there needs to be some action a taken around the applied practice of fatigue management.

7.2.3.1 Implementation regime

Firstly, an implementation regime for fatigue management projects should be considered to be prepared for when a fatigue management related performance question arises. I propose the physiologist within the sport in question leads on such a plan. If there is no physiologist within the sport, then I suggest an appropriate practitioner should take the lead with close collaboration with myself, the sleep PhD student and associated academics, as the experts on fatigue management. Evidence of this working well was in the sport of Rugby 7's where the strength and conditioning coach led the sleep project internally with the sport but liaised closely with my sleep PhD student for the duration of the sleep project.

In leading an implementation regime for fatigue management projects, the physiologist should proactively consider where data capture of sleep and movement behaviour should exist in a sport's performance programme and an athlete's overall assessment battery. I propose a proactive approach works best in terms of collating baseline data, under normal training circumstances, as athletes enter a world class performance programme. This negates problems in establishing 'baseline' data if difficulties with sleep or associated movement behaviour arise. A good example of this is evidenced in my work with British Rowing, where, following some reactive projects conceived when some of the rowers were experiencing poor sleep, the British Rowing Chief Medical Officer requested the entire senior squad (Open weight men, women and lightweight and Paralympic classes) be screened for baseline sleep and movement behaviour at the beginning of the 2011/12 season. Given this was 'Olympic/Paralympic year', this was a positive message to send to the rowers about the importance of their fatigue management and a great sense of personal pride for me in the work I had completed to date in the area. The challenge was screening over 60 athletes with limited resources, but this was achieved through prioritising athletes and loaning equipment.

In implementing fatigue management projects, ideally every sport would have a physiologist with unlimited resources, tools and knowledge at their disposal to capture data on sleep and associated movement behaviour. However, in reality this is not the case. Therefore, where practitioners screen athlete's sleep, and associated movement behaviour, for baseline values as part of their assessment battery, there also needs to be an acknowledgement of how this can be delivered with limited personnel with specific knowledge on the concept of fatigue management. Through the workshops I designed, delivered and managed (described throughout this thesis), most Olympic and Paralympic sports employed practitioners with a basic knowledge of sleep and movement behaviour and who had been trained in using Actigraphy. This allowed sports to at least capture data on sleep and associated movement behaviour, with a view that detailed analysis could be sought from experts in the field, including myself and my sleep PhD student.

In implementing fatigue management projects, sports also need to consider deploying support staff to measure fatigue management relative to their time taken in other activities or areas of support within their work programme. This is where a sport's coaches, performance directors, administrators and practitioners need to closely collaborate on prioritising projects within their WITTW model and examining project demands against practitioner time available. This relies on a high level of self-awareness from the practitioners and a level of pragmatism, from those involved in a sports WITTW model, as to what can be delivered to a world class level, in what time frames and under what circumstances. Further, the 'EIS Hierarchy of Needs' and 'Decision Tree' presented in Chapter 6, were designed to assist practitioners in prioritising and deciding the best course of action to implement their fatigue management projects. An example of this is through my work with British Rowing where I had a responsibility to not only assess the sleep and movement behaviour of the entire rowing squad (Olympic and Paralympic), but also lead on the high performance sport system wide dissemination of fatigue management knowledge. I capably delivered on all aspects of this particular rowing project through good planning, communication with colleagues and expectation management on the part of the coaches and athletes.

Any implementation regime for fatigue management projects should also consider a prioritisation phase preceding any data collection. Reflecting on the priority of assessing fatigue management in a sports performance programme means evaluating its impact relative to other factors in the sports WITTW model. This is another reason for the physiologist to lead on the area given their awareness and understanding of the determinants of performance for a given sport and the physical demands of delivering such determinants.

I have maintained throughout this thesis that sleep and associated movement behaviour are impact factors on determinants of performance i.e. 'what it takes to win'. Whilst it is difficult in a WITTW model to estimate what the performance benefit might be for an athlete who currently has sub-optimal fatigue management, it is possible to state that even a small amount of accumulated poor sleep will undoubtedly have a greater effect on performance. I describe this to coaches using the analogy of 'hydration' and its effects on performance. That is, being dehydrated by even as little 2% of body weight degrades aerobic exercise performance in temperate-warm-hot environments and that greater levels of dehydration can further degrade aerobic exercise performance (American College of Sports Medicine, 2007), and these negative effects can add (or even multiply). The same can be said for sleep and movement behaviour, in that athletes may sustain negative fatigue management factors and patterns for multiple weeks during their athletic career and small decrements in such factors may have a more significant effect on performance. As athletes move from competition to competition, the benefit of modifying these factors could reasonably enhance their performance by more than, for example, 1%. One can reasonably assume then that placings outside of medal positions could become medal winning places (e.g. 4th to Silver), for the sake of reversing small negative impact factors on determinants of performance.

Of course, any consideration and implementation of data capture within a world class performance programme, holds the caveat of 'competitive advantage'. That is, any knowledge gain and dissemination of fatigue management would need a strategic output post the current Olympic/Paralympic cycle to maintain a competitive advantage over opposing nations. Regardless, focusing on fatigue management as a concept in a Sports Science practitioner's assessment battery and addressing the balance of practitioner time to implement projects on it, will ensure world class service provision is current, pioneering and persistent in seeking the winning advantage in an aggressively competitive industry.

7.2.3.2 Training

Moving forward, the lack of personnel with specific knowledge of sleep and movement behaviour, would be helped by neophyte practitioners being trained from undergraduate level onwards on what fatigue management is and the objective and subjective methods available to assess it. As physiology practitioners, we should take responsibility for this education in addition to reasons, already outlined throughout this thesis, for us to 'own' the area of sleep and athletic performance. This would ensure that when practitioners embark on a career in the applied field, they have a comprehensive understanding and battery of assessments, which would include fatigue management, that they could deploy when supporting an athlete(s) in overcoming marginal losses and attaining successful performances on the international stage.

However, an increased emphasis, in Sport and Exercise Science undergraduate degree courses, on the physiology of sleep and its effects on athletic performance would involve a change of practice across the Sport and Exercise Science academia. This is primarily because sleep physiology is often taught generically in healthcare science degrees, but only as a small section of a respiratory physiology module. Table 7.7 illustrates how practitioners could progress their knowledge and awareness of fatigue management (measurement and assessment) from university undergraduate course through to a career in the applied field.

Table 7.7 The process for progressing practitioner knowledge and awareness of fatigue management (measurement and assessment) from university undergraduate course through to a career in the applied field.

Stage of career	Development of knowledge
• Undergraduate student (very limited experience in working in the applied field)	• Basic sleep physiology as part of undergraduate degree curriculum • Basic introduction to sleep and athletic performance • Some introduction and awareness of measurement techniques for sleep and movement behaviour
• Neophyte practitioner/post-graduate student (e.g. year one in post or studying alongside volunteer work in performance sport)	• Limited experience working generically in the applied field • Limited understanding of fatigue management (and therefore assessing sleep or movement behaviour) • Limited understanding of 'What it Takes to Win' models and the impact factors on them e.g. fatigue management • Introduction to practical assessment methods for fatigue management (sleep and movement behaviour)
• Applied practitioner (e.g. 1 Olympic cycle experience)	• Evolving understanding of fatigue management assessment techniques • Motivated to learn about sleep and movement behaviour and their ability to impact on 'What it Takes to Win' factors • Competent in assessment methods for sleep and movement behaviour • Interpretation of sleep and movement behaviour data with supervision

• High performance sport applied practitioner (e.g. several Olympic cycles experience)	• Expert knowledge in fatigue management • A thorough understanding of how fatigue management can impact on 'What it Takes to Win' factors • Experienced in measurement and analysis of sleep and movement behaviour • A high level of experience in assessment methods for sleep and movement behaviour and interpretation of data. • Strives to establish baseline data of sleep and movement behaviour characteristics of the elite athletes they have responsibility for • Developed a network of experts to collaborate with on matters relating to sleep and movement behaviour e.g. medic, psychologist • Disseminates knowledge gained of fatigue management to the wider high performance sport network • Acknowledges boundaries but leads a multidisciplinary team in matters relating to fatigue management in their sport(s) • Involved in research for further understanding of fatigue management (in high performance sport)

In striving to be world class in their field, as with any other physiological concept, neophyte practitioners would need to understand the importance of collaboration with colleagues in other disciplines when considering fatigue management. Specific training of novice physiologists of fatigue management practices would ensure practitioners have the awareness and skill set to collaborate with other members of an athletes' Science and Medicine support team. As described in Chapters 3, 4 and 6, whilst physiologists can take responsibility for the measurement and assessment of sleep, any interventions to improve it need to be formed through interaction with other Sports Science and Medicine practitioners. In short, an absolute multidisciplinary approach is necessary for successful fatigue management practices. Contemporary examples of where this has worked well need to be showcased in order to encourage those in the UK high performance sport industry to focus, where relevant, on fatigue management in the multidisciplinary team work flows.

Of note, one avenue to achieve Sport and Exercise Science undergraduate courses engaging with fatigue management as part of their teaching, would be to collaborate with the British Association of Sport and Exercise Sciences (BASES). They govern a BASES Undergraduate Endorsement Scheme (BUES), which is a recognised standard for all Sport and Exercise Science undergraduate degree programmes and would provide a useful framework to guide fatigue management into undergraduate courses.

7.2.3.3 Non-technical skill set

It is also important to have someone within sport's performance programmes to drive the fatigue management initiative forward in terms of recognising it as a concept to impact on a sport's WITTW model. For reasons already outlined, physiologists are ideally technically suited to this role. Yet parallel to the technical reasons as to why physiologists should lead on fatigue management projects, is the dialogue the physiologist has with their athletes, coaches and support staff within a sport's performance programme. By this I refer to the fact that the measurement of athlete sleep and associated movement behaviour are areas of their recovery that remain quite private and are not traditionally monitored (refer to Chapter 1). Therefore, there is a case that, as physiologists, we need to focus our skill set on an ability to engage with athletes in a manner in which they subscribe to the measurement and analysis of any part of their training and recovery, including sleep and associated movement behaviour. A prerequisite for practitioners is to therefore have the 'non-technical' skills (e.g. communication, intuition and patience), to be able to hold a dialogue with athletes (and coaches) to gain an understanding of an individual athlete's training load and the impact on their perception of fatigue. Whilst the objective and subjective assessment methods for fatigue management described in this thesis offer valuable information, an ability to talk to athletes and gain their trust would add impact on a practitioner's ability to provide effective fatigue management support where technological resources are limited and self-reporting of sleep can be subject to untruths. Following on from gaining trust with an athlete regarding assessment of their fatigue management, is perhaps the opportunity for physiologists to take the lead on such a topic in cross-discipline meetings with coaches and other Sports Science and Medicine support staff.

Similarly, if the physiologist has trust and credibility within the sport's performance programme, the ability to evolve a concept such as fatigue management becomes a much simpler process. This is demonstrated in my work with British Rowing where I was an established member of the Sport Science and Medicine team. As such, I had the trust and respect of coaches and athletes and collaborated well with the sport's Chief Medical Officer to ensure fatigue management was a proactive, focal and routine part of the rowers' assessments.

In terms of fatigue management communication between practitioner, athlete and coach, the simplicity of the actigraphy technology is also an advantage in that it allows a dialogue about fatigue management to be opened between support staff, athlete and coach that may otherwise not have occurred. As one interviewee stated, “the ‘[sleep] technology is quite sophisticated now, where you could probably monitor weeks of data, and an athlete would not really bat an eyelid, or won't complain about the tools that they're kind of being used to measure them”.

Generically, as Sports Science and Medicine practitioners, we also need to consider increasing the priority of fatigue management in more detail. For example, more routinely we need to scrutinise athletes’ movement behaviour (downtime) which will allow us to objectively demonstrate to an athlete if their downtime is insufficient. This process also opens a dialogue with an athlete as to what they consider useful downtime practices to be and how they can modify such practices to optimise recovery between training sessions. Table 7.8 outlines some of the feedback from the interviewees regarding movement behaviour assessment.

Table 7.8 Feedback from the interviewees regarding movement behaviour assessment.

P4 ‘’It [movement behaviour analysis] gives you a good indication of lifestyle, from looking at the actigraphy read-outs’’.
P4 ‘’The movement and the behaviour around that, and a lot of the time it is providing objectivity to subjective instinct of what's already going on, but that's important, because it [fatigue management] can start a conversation on an objective footing. I think eventually we will probably get to a stage where we can really evaluate that [movement behaviour] from an objective perspective, but it's more round what you do in an intervention context to accelerate sleep profiles, and that could be something as simple as changing the temperature in a bed’’.
P4 ‘…. a specific example where we [coaches and Sports Science and Medicine support team] purposely set out on one of our training camps to frontload the tourist time trips in Brazil, and another key question for me was understanding the energy transfer. So everybody's got an energy budget. Would that energy budget be severely depleted in an uncontrolled noisy, hot Rio de Janeiro, having come from a quiet, controlled Belo Horizonte, and would that be reflected in sleep profiles and the activity profiles. Yes, it was, and the decision that we did in terms of frontloading or tourist attractions was reflected in that information, which can now be put to bed and coaches are aware of that. Time on feet is an issue, and it's something that we need to be mindful of, and that information via myself to the British Olympic Association has enabled us [Sport] to ensure that we have specific bus times and routes from our hotel to the Olympic venue, even though it's a twenty-minute

walk. Ordinarily that's not a lot, but when you add it up, it can be. Indirectly it has had an impact.''

P3 ''….on the movement behaviour side, I think again, it's a really powerful tool, in the sense that obviously, when athletes finish training, and obviously they go to a certain mode, whether that mode for them is optimal, I suppose it's [movement behaviour] open to question, and I think again, something as simple as wearing a watch that is tracking their movement, something again, very simple, and again, can be taken for granted, and again opens that dialogue of, "Well, yes, you're not doing particularly well in this part of your performance. Maybe this is something that you could address", or maybe, "It's absolutely fine. Do not worry about it", but again, it opens that dialogue''.

P2 ''I think generally, that recovery's better. I think all the rowers go through periods of time when they're frantically busy, and I think what they do learn is that when they're at home, they need to watch their time. We [coaches and Sports Science and Medicine support team] have them captive on training camp, and that's relatively easy, but when they're at home they can try and pack everything in, which is understandable, but it's at a price. So I think those have been exposed to the data, and have had their sleep hygiene etc., are more willing to try and organise their lives slightly differently''

7.2.4 Future strategy

Having described the evolution of the concept of fatigue management in the UK high performance industry, and made recommendations for future improvement in this thesis, such proposals then necessitate a strategic direction for further concept evolution. The EIS sleep strategy for the Tokyo 2020 Olympic/Paralympic cycle, which I wrote, and described in Chapter 6, aimed to provide such direction (available in Appendix 4).

Specifically, now I have raised awareness of the concept, it is necessary to have a more targeted approach in terms of where fatigue management, particularly regarding sleep, can add value. In addition, there is a need to integrate sleep profiling with other metrics that can help improve athletic performance and disseminate information regarding fatigue management in a more effective manner. That is not to say that what has been delivered so far has not been valuable, but there now needs to be a more strategic means of delivering basic information and renewed or revised knowledge to new practitioners, for example, smart phone applications, webinars and social media links.

Implementing a more strategic profiling of elite athletes' fatigue management whether it be sleep, movement behaviour or both, can be achieved through a more consultative approach. Team GB's travel strategy for Tokyo 2020 is an example of such a method. Sports were able to access the knowledge for how to gather intelligence regarding individual athlete travel responses over multiple time zones through using mine and my PhD student's knowledge in the area of sleep and athletic performance. In addition, I personally have been approached in a consultant capacity to support private sector sleep projects and have started to write blogs focusing on fatigue management in the workplace, e.g. pregnancy and professional studies at work (Gilchrist, 2017a & Gilchrist, 2017b). Table 7.9 provides some quotes from interviewees regarding the future directions for the concept of fatigue management.

Table 7.9 Interviewee quotes relating to future directions for fatigue management

P2 'one way to do it [develop fatigue management] may be to have disseminated more information back to the physiologists here, and make sure that they actually then presented broader. Because our [Sports Science and Medicine support team] challenge is that the coaches need to be engaged with anything that we're [Sports Science and Medicine support team] trying to change or impose on the athletes, and dare I say, I think that sometimes that's a stumbling block in this particular sport, that it might get to them, but doesn't get any further. So outside of that, I guess maybe, because I sit where I do, sometimes stuff that's going on within the EIS doesn't get out. So I'm not an EIS practitioner, so if there's any kind of dissemination of information, it doesn't necessarily get to me, and I'm sure that's true of other sports like us who sit slightly outside it. So I do not know whether there's a way to disseminate further things that do get disseminated within the EIS structure to anyone who's got a UK Sport kind of basis''. P5 ''There was a gain to be achieved simply by formally introducing sleep science into sports science, in a way that allowed sleep science to grow in this area, so that if we could foster interest in sleep science, then we cannot only gain immediately, but we could leave a legacy, and there may be something we'd develop from this''.

7.3 Summary

Throughout this thesis I have described my own personal development in the area of fatigue management as part of the evolution of the concept to the UK high performance sport industry. As a young neophyte practitioner, my technical skill set was fairly generic having followed the traditional Sports Science under and post-graduate degree courses. As I have worked through the UK high performance sport system and become more senior within my professional roles, I have specifically developed my knowledge of recovery, in particular sleep and associated movement behaviour. I am proud of the fact I have taken hold of the concept of fatigue management, and 'owned' it as part of my work programme. This has allowed me to direct specific avenues to educate and disseminate information about the topic to peers, athletes and coaches, in addition to developing my own personal expertise in the area (as described in Chapter 6).

Further, fatigue management as a concept has evolved at a time where Sports Science (and Medicine) disciplines have developed as integral components in the discussions of a sport's WITTW model. Therefore, having an area of expertise that impacts on all aspects of WITTW is a powerful skill set to have in a growing industry. I am confident that having this knowledge base as my particular 'technical area' has facilitated my development from a generic 'sports scientist' to a senior 'technical lead', and now consultant, within the UK high performance sport industry and beyond.

Fatigue management, through the assessment of sleep and movement behaviour for athletic performance, is a novel concept in the consideration of factors impacting athletic performance. It is not the single variable that will ensure an athlete wins, there are a myriad of factors, but without doubt, it will have an impact. The whole concept of fatigue management (measurement, analysis and strategies to optimise athlete sleep and downtime) hasn't necessarily been addressed in traditional physiological support to elite athletes, but it will make a difference, whether it's a napping intervention, or strategies to optimise nocturnal sleep, for example. Certainly, the examples in this thesis, alongside subjective feedback from interviewee participants, suggest that the impact of introducing the concept of fatigue management to the high-performance industry has been great and, importantly, changed practice.

Further projects have followed since those described in this thesis and we have been able to impact the high-performance sport system on a wider scale. For example; advising Team GB and Team Paralympics GB on their sleep and travel plans for the Rio 2016 and Tokyo 2020 Olympic and Paralympic Games, developing research opportunities, technologies and presenting at national and international conferences. Additionally, the multitude of requests from Sports for assistance with fatigue management, coupled with the obvious requirement for practitioner education on the topic, only highlights the positive impact this process has had within the UK high-performance sport industry.

Increased awareness and education of the concept to practitioners, athletes and coaches, mean that the UK high performance system as a whole is now far more knowledgeable of how fatigue management can impact on a sports' determinants of performance. Therefore, I have focused the evolution of this concept to the UK high performance sport system, as an important and pioneering area for consideration in planning WITTW models. I am encouraged by findings in my work with athletes, the wider literature and the demand for fatigue management projects, which strengthen my belief of the impact of sleep and associated movement behaviour on WITTW models and ultimately, performance.

It is through my leadership that the concept of fatigue management has been engaged with by peers within the UK high performance sport sector, particularly those responsible for sport specific models to determine performance. It is my hope that, as a result of the outlined evolution of the concept, sports projects delivered, research conducted and evolving contemporary innovations, I have left a legacy within the EIS and wider UK high performance industry, for the concept of fatigue management to be recognised as a factor affecting 'What it Takes to Win' models and that this can then aid the translation of marginal gains into winning more medals.

References

1. Abeln, V., Kleinert, J., Strüder, H, K., Schneider, S. (2013). Brainwave entrainment for better sleep and post-sleep state of young elite soccer players - A pilot study. *European Journal of Sport Science*, 14:5, 393-402.

2. Aadahl, M & Jorgensen, T. (2003). Validation of a new self-report instrument for measuring physical activity. *Medicine and Science in Sport and Exercise,*35(7),1196-202.

3. American academy of sleep medicine and sleep research society. (2015). Recommended amount of sleep for a health adult: a joint consensus statement of the American academy of sleep medicine and sleep research society. *Sleep*, 8(6), 843-844.

4. American College of Sports Medicine, Sawka, M., N, Burke, L., M, Eichner, E., R, Maughan, R., J, Montain SJ, Stachenfeld N., S. (2007). American College of Sports Medicine position stand. Exercise and fluid replacement. *Medicine and Science in Sport and Exercise*, 39(2),377-90.

5. Anderson, A., Miles, A., Maconey, C. & Robinson, P. (2002). Evaluating effectiveness of applied sport psychology practice: making the case for a case study approach. *The Sport Psychologist*, 16, 432-453.

6. Anderson, A., Knowles, Z., & Gilbourne, D. (2004). Reflective practice for sport psychologist: Concepts, models, practical implications and thoughts on dissemination. *The Sport Psychologist*, 18, 188-203.

7. Ahrberg, K., Dresler, M., Niedermaier, S., Steiger, A. & Genzel, L. (2012). The interaction between sleep quality and academic performance. *Journal of Psychiatric Research*, 46(12), 1618-1622.

8. Baker, F., C & Driver, H., S. (2007). Circadian rhythms, sleep, and the menstrual cycle. *Sleep Medicine*, 8(6), 613-22.

9. Banks, S & Dinges, D., F. (2007). Behavioral and physiological consequences of sleep restriction. *Journal of Clinical Sleep Medicine*, 3(5), 519-528.

10. Barlow, M. 2012. Special report: Why mixing caffeine and sleeping pills is dangerous for England players [Online]. Available from: http://www.dailymail.co.uk/sport/football/article-2219861/Mixing-caffeine-sleeping-pills-dangerous-England-players.html. [Accessed February 2014].

11. Besedovsky, L., Lange, T & Born, J. (2012). Sleep and immune function. *European Journal of Physiology*, 463, 121-137.

12. Biddle S., J, Markland D., Gilbourne D., Chatzisarantis N., L., Sparkes A., C. (2001). Research methods in sport and exercise psychology: quantitative and qualitative issues. *Journal of Sports Sciences,* 19(10),777-809.

13. Bishop D. J., (2004). The effects of travel on team performance in the Australian national netball competition. Journal of science and medicine in sport / Sports Medicine Australia, 7 (1), 118-22.

14. Bishop D. J., *et al.* (2006). Sports-science roundtable: does sports-science research influence practice? *International Journal of Sports Physiology Performance*, 1(2), 161-8.

15. Borbély, A., A. (1982). A Two Process Model of Sleep Regulation. *Human Neurobiology*, 1(3), 195-204.

16. Borbély, A., A., Daan, S., Wirz-Justice, A. & Deboer, T. (2016). The two-process model of sleep regulation: a reappraisal. *Journal of Sleep Research*, 25: 131–143.

17. Boonstra, T., W., Stins, J., F., Daffertshofer, A. & Beek, P., J. (2007). Effects of sleep deprivation on neural functioning: an integrative review. *Cellular and Molecular Life Sciences*, 64, 934–946

18. Brailsford, D. in Stevenson, J. 2013. Sir Dave Brailsford on marginal gains and that Froome-Wiggins rivalry Road.CC [Online], 23 September. Available from: http://road.cc/content/news/94528-sir-dave-brailsford-marginal-gains-and-froome-wiggins-rivalry. [Accessed March 2015].

19. Breus, M., J. O'Conner, P., J. & Raga, S., T. 2000. Muscle pain induced by novel eccentric exercise does not disturb the sleep of normal young men. *The Journal of Pain*, 1(1), 67 – 76.

20. Brink, M. S., Visscher, C., Coutts, A. J., Lemmink, K. A. P. M. (2012). Changes in perceived stress and recovery in overreached young elite soccer players. Scandinavian Journal of Medicine & Science in Sports, 22(2), 285-292(8).

21. British Association of Sport and Exercise Sciences. 2014. Understanding your client (core workshop) [online]. Available from: www.bases.org.uk/Workshops/Understanding-Your-Client-Core-4-workshop-for-those-in-second-half-of-Supervised-Experience-University-of-Central-Lancashire/21325 [Accessed October 2014]

22. Broomfield, N., Espie, C., MacMahon, K., Macphee, L., & Taylor, L. (2006) The attention-intention-effort pathway in the development of psychophysiologic insomnia: A theoretical review. *Sleep Medicine Reviews*, 10, 215-245.

23. Burch, N. in Adams, L. 2011. Learning a new skill is easier said than done. [online]. Available from http://www.gordontraining.com/free-workplace-articles/learning-a-new-skill-is-easier-said-than-done/ [Accessed October 2014]

24. Buysse, D.J., Reynolds III, C.F., Monk, T.H., Berman, S.R., & Kupfer, D.J. 1988. The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Journal of Psychiatric Research, 28*(2), 193-213.

25. Byrne., P. 2017. The trouble with sleep watches. [Online]. Available from: http://byrne-co.com/the-trouble-with-sleep-watches/ [Accessed 31st October 2017].

26. Caia, J., Thornton, H. R., Kelly, V. G., Scott, T.J., Halson, S. L., Cupples, B. & Driller, M. W. (2017) [Online]. Does self-perceived sleep reflect sleep estimated via activity monitors in professional rugby league athletes? *Journal of Sports Sciences,* 1-5 [Accesses 1st November 2017].

27. Chennaoui, M., Arnal, P., J., Sauvet, F., Leger, D. 2015. Sleep and exercise: A reciprocal issue? *Sleep Medicine Reviews,* 20, 59-72.

28. Chennaoui, M., Bougard, C., Drogou, C., Langrume, C., Miller, C., Gomez-Merino, D., & Vergnoux, F. (2016). Stress Biomarkers, Mood States, and Sleep during a Major Competition: “Success” and “Failure” Athlete’s Profile of High-Level Swimmers. *Frontiers in Physiology*, *7*, 94.

29. Cohen, S., *et al.* (2009). Sleep Habits and Susceptibility to the Common Cold. *Archives of Internal Medicine*, 169(1), 62–67.

30. Czeisler, C. & Fryer, B. 2006. Sleep Deficit: The Performance Killer. [Online]. Available from: https://hbr.org/product/sleep-deficit-the-performance-killer-a-conversation-with-harvard-medical-school-professor-charles-a-czeisler/R0610B-PDF-ENG [Accessed online February 2015].

31. Clegg, S. in Kelso P. 2012. London 2012 Olympics: How Team GB went from zeroes to heroes after Atlanta '96 low point. The Telegraph [Online], Available from: http://www.telegraph.co.uk/sport/Olympics/Team-GB/9432637/London-2012-Olympics-How-Team-GB-went-from-zeroes-to-heroes-after-Atlanta-96-low-point.html [Accessed October 2014].

32. Clark, A & Moss, P. (2011). Listening to Young Children: The Mosaic approach. National Children's Bureau.

33. Clarke D.C. & Skiba P.F. (2013). Rationale and resources for teaching the mathematical modelling of athletic training and performance. *Advances in Physical Education,* 37(2), 134-52

34. Cohen D. & Crabtree B. (2006). Qualitative Research Guidelines Project. http://www.qualres.org/index.html.

35. Cohen S., Doyle W., J., Alper C., M., Janicki-Deverts D. & Turner R., B. (2009). Sleep habits and susceptibility to the common cold. *The International Archives of Medicine,* 169(1), 62-7.

36. Colwell, C. Presentation. [Verbal communication: May 2013]. American College of Sports Medicine Annual Meeting.

37. Cropley, B., Miles, A., Hanton, S., & Anderson, A. (2007). Improving the delivery of applied sport psychology support through reflective practice. *The Sport Psychologist*, 21, 475-494.

38. Cropley, B., Hanton, S., Miles, A., & Niven, A. (2010). The value of reflective practice in professional development: an applied sport psychology review. *Sports Science Review,* 19, 179-209.

39. Cropley, B., & Hanton, S. (2011). The role of reflective practice in applied sport psychology: Contemporary issues for professional practice. In S. Hanton & S. D. Mellalieu (Eds.) Professional practice in sport psychology. A review. London: Routledge, pp. 307-336.

40. Culver, D. M., Gilbert, W., & Trudel, P. (2003). A decade of qualitative research in three sport psychology journals: 1990-1999. *The Sport Psychologist,* 17*,* 1-15.

41. Culver, D., M., Gilbert, W., Sparkes, O. (2012). Qualitative Research in Sport Psychology Journals: The Next Decade 2000-2009 and Beyond. *The Sport Psychologist*, 26, 261-281.

42. Davenne, D. (2009). Sleep of athletes – problems and possible solutions. *Biological rhythms research,* 40(1), 45-52.

43. Davison, R., R, Van Someren K., A. & Jones A., M. (2009). Physiological monitoring of the Olympic athlete. *Journal of Sports science,* 27(13), 1433-42.

44. Davison R. C. & Williams M. A. (2009). The use of sports science in preparation for Olympic competition. *Journal of Sports science s,* 27(13), 1363-1365.

45. De Bosscher, V. *et al.* (2009). Explaining international sporting success: An international comparison of elite sport systems and policies in six countries. *Sport Management Review,* 12, 113–136.

46. Dick T.E., Feng P. (2014) Neurophysiology of Sleep. In: Competencies in Sleep Medicine. Springer, New York, NY.

47. Drake, Christopher L., Scofield, H. & Thomas, R. 2008. Vulnerability to insomnia: The role of familial aggregation. *Sleep Medicine*, 9(3), 297 – 302.

48. Drew, M., K. & Finch, C., F. (2016). The Relationship Between Training Load and Injury, Illness and Soreness: A Systematic and Literature Review. *Sports Medicine*, 46(6), 861-883.

49. Driller, W., M., Mah, D., C. & Halson. L., S. (2018). Development of the athlete sleep behaviour questionnaire: A tool for identifying maladaptive sleep practices in elite athletes. *Sleep Science*, 11(1), 37-44.

50. Ekblom O., Nyberg, G., Ekblom Bak, E., Ekelund, U. & Marcus, C. (2012). *Journal of Physical Activity and Health,* 9, 389-393.

51. English Institute of Sport. 2013. About the EIS. [Online]. Available from: http://www.eis2win.co.uk. [Accessed 18 October 2013).

52. English Institute of Sport. 2018. Athlete Health. [Online]. Available from: http://www.eis2win.co.uk. [Accessed 18 March 2018).

53. Erlacher, D., Ehrlenspiel, F., Adegbesan, O, A., El-Din, H, G., (2001). Sleep habits in German athletes before important competitions or games. *Journal of Sports Sciences,* 29(8), 859-866.

54. Esser, K. Presentation. [Verbal communication: May 2013]. American College of Sports Medicine Annual Meeting.

55. Fallon, K., E. (2007). Blood tests in tired elite athletes: expectations of athletes, coaches and sport science/sports medicine staff. *British Journal of Sports Medicine*, 41, 41-44.

56. Faraut, B., Boudjeltia, K., Dyzma, M., Rousseau, A., David, E., Stenuit, P., Franck, T., Van Antwerpen, P., Vanhaeverbeek, M. & Kerkhofs, M. (2011). Benefits of napping and an extended duration of recovery sleep on alertness and immune cells after acute sleep restriction. *Brain, Behaviour, and Immunity*, 25, 16-24.

57. Fullagar, H., H., K., Skorski, S., Duffield, R. Hammes, D., Coutts, A., J. & Meyer, T. (2015). Sleep and Athletic Performance: The Effects of Sleep Loss on Exercise Performance, and Physiological and Cognitive Responses to Exercise. *Sports Medicine* (45) 161-186.

58. Fietze, I., Strauch, J. & Holzhausen, M. (2009). Sleep quality in professional ballet dancers. *Chronobiology International,* 26(6), 1249-62.

59. Forbes-Robertson, S., Dudley, E., Vadgama, P., Drawer, S. & Kilduff, L. (2015). Circadian Disruption and Remedial Interventions Effects and Interventions for Jet Lag for Athletic Peak Performance. *Sports Medicine*, 45(2), 161-186.

60. Frank, M. G. & Benington J. H. (2006). The role of sleep in memory consolidation and brain plasticity: dream or reality? *Neuroscientist,* Dec; 12(6), 477-88.

61. Fullagar, H., K., Skorski, S., Duffield, R., Hammes, D., Coutts, A. J. & Meyer, T. (2015). Sleep and Athletic Performance: The Effects of Sleep Loss on Exercise Performance, and Physiological and Cognitive Responses to Exercise. *Sports Medicine 45(2), 0112-*1642.

62. Galambos, N., L., Howard, A., L. & Maggs, J., L. (2011). Rise and Fall of Sleep Quantity and Quality With Student Experiences Across the First Year of University. *Journal of Research on Adolescence,* 21(2), 342-349.

63. Gandhi, A., V., Mosser, E., A., Oikonomou, G & Prober, D., A. (2015). Melatonin is required for the circadian regulation of sleep. *Neuron,* 85, 1193-1199.

64. Gibbs, G. (1988) *Learning by Doing: A guide to Teaching and Learning Methods.* Oxford: Further Education Unit, Oxford Polytechnic.

65. Gibson, O. 2016. Team GB's Olympic success: five factors behind their Rio medal rush. The Guardian [Online]. Available from: https://www.theguardian.com/sport/blog/2016/aug/15/five-factors-team-gb-Olympic-success-medal-rush [Accessed 19th March 2018].

66. Gilchrist, S., L. Presentation. [Verbal communication: Nov 2016]. Sleep and movement behaviour characteristics of an international olympic rowing squad and the influence of domestic living location. BASES Conference.

67. Gilchrist, S., L. 2017a. Are you ready for pregnancy in the workplace? [Online]. Available from: https://www.theperformanceroom.co.uk/blog. [Accessed 20th March 2017].

68. Gilchrist, S., L. 2017b. Are you ready for studying in the workplace? [Online]. Available from: https://www.theperformanceroom.co.uk/blog. [Accessed 20th March 2017].

69. Gonnissen, H. K., Adam, T. C., Hursel, R., Rutters, F., Verhoef, S. P. & Westerterp-Plantenga, M. S. (2013). Sleep duration, sleep quality and body weight: parallel developments. *Physiology Behaviour* 10, 121:112-6.

70. Greenleaf, C. Gould, D. & Dieffenbach, K. (2001). Factors Influencing Olympic Performance: Interviews with Atlanta and Negano US Olympians. *Journal of Applied Sport Psychology*, 13(2), 154-184.

71. Gupta, L. Presentation to the author. [Personal Communication: December 2013].

72. Gupta, L. Letter from the author. [Personal Communication: February 2015].

73. Gupta, L., Morgan, K. & Gilchrist, S. Sports Medicine. (2016). Does elite sport degrade sleep quality? A systematic review. *Sports Medicine*. 1-17.

74. Gupta, L., Morgan, K. & Gilchrist, S. (2017). Between sport differences in sleep quality and insomnia symptomology: a national survey of British athletes. *Sleep,* 40 (suppl_1): A123-A123.

75. Gupta, L., Morgan, K. & Gilchrist, S. (2017). Between sport differences in sleep quality and insomnia symptomology: a national survey of British athletes. *Sleep,* 40 (suppl_1): A123-A123.

76. Gupta, L., Morgan, K. & Gilchrist, S. (2017). Physiological sleep tendency and sleep reactivity among elite athletes. *Sleep,* 40 (suppl_1): A70-A71.

77. Gupta, L. (2017). Presentation. [Personal communication: October 2017].

78. Hahn A. (2013). Introduction. In: Tanner, R. T. & Gore C. J. ed. *Physiological tests for Elite Athletes. Australian Institute of Sport.* 2nd Ed. Human Kinetics, xii-xiv.

79. Harris, Cameron. (2006). Neurophysiology of sleep and wakefulness. *Respiratory care clinics of North America,* 11, 567-86.

80. Halcomb, E., J. & Davidson, P., M. (2006) Is verbatim transcription of interview data always necessary? *Applied Nursing Research,* 19(1), 38-42.

81. Halson, S., L. 2008. Nutrition, sleep and recovery. *European Journal of Sport Science*, 8(2), 119-126.

82. Halson, S. L. (2014). Sleep in Elite Athletes and Nutritional Interventions to Enhance Sleep. *Sports Medicine*, 44 (1), S13–S23.

83. Halson, S. L. (2014). Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine*, 44 (2), S139-S147

84. Hardy, L., Gould, D. & Jones, J., G. (1996). *Understanding psychological preparation for sport: theory and practice of elite performers.* Chichester: Wiley.

85. Hausswirth, C., Louis, J., Aubry, A., Bonnet, G., Duffield, R. & Le Meur, Y. (2014). Evidence of disturbed sleep and increased illness in overreached endurance athletes. *Medicine and Science in Sport and Exercise,* 45(5), 1036-1045.

86. Hawkes, E., Z. and Miles, A. (2001). Evaluating the effectiveness of British sports physiology consultants. (unpublished MSc Coaching Science Thesis). University of Wales Institute Cardiff, Cardiff, UK.

87. Hirshkowitz, M., Whiton, K., Albert, S. M. *et al.* (2015). National Sleep Foundations updated sleep duration recommendations: final report. *Sleep Health,* 1, 233-243.

88. Hoy, C. in Kelso P. (2012). London 2012 Olympics: Government guarantees athlete funding to 2016. The Telegraph [Online], 12 August. Available from:

http://www.telegraph.co.uk/sport/Olympics/9470453/London-2012-Olympics-Government-guarantees-athlete-funding-to-2016.html [Accessed March 2014].

89. Horne, J.A. and Ostberg, O., (1975). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology*, *4*(2), pp.97-110.

90. http://www.howsleepworks.com/images/hypnogram.jpg [Online]. Accessed October 2017.

91. Irwin, M. (2002). Effects of sleep loss on immunity and cytokines. *Brain, Behaviour and Immunity*, 16, 503-512.

92. Isabella, L., A. (1990). Evolving interpretations as a change unfolds: How managers construe key organizational events. *Academy of Management Journal*, 33(1), 7-41.

93. Ji, X., and Liu, J. (2016) Subjective sleep measures for adolescents: a systematic review. *Child: Care, Health and Development*, 42: 825–839.

94. Johns, M., W. (1990). A New Method for Measuring Daytime Sleepiness: The Epworth Sleepiness Scale. *Sleep,* 14(6), 540-545.

95. Johnston, I. (2017). 'Catastrophic' lack of sleep in modern society is killing us, warns leading sleep scientist. The Independent [Online], 24th September. Available from: https://www.independent.co.uk/news/sleep-deprivation-epidemic-health-effects-tired-heart-disease-stroke-dementia-cancer-a7964156.html [Accessed June 2018].

96. Juliff, L. E., Halson, S. L. & Peiffer, J., J. (2015). Understanding sleep disturbance in athletes prior to important competitions. *Journal of Science and Medicine in Sport*, 18(1), 13-18.

97. King, C. (1980). Sleep Hypnogram and Sleep Analysis: A Rapid, Inexpensive Procedure. *Sleep*, 3(1), 93-94.

98. Kloss, J., D, Perlis, M., L, Zamzow, J., A, Culnan, E., J & Gracia C., R. (2015). Sleep, sleep disturbance, and fertility in women. *Sleep Medicine Reviews,* 22, 78-87.

99. Knowles, Z, Gilbourne, D., Borrie, A. & Nevill, A. (2001). Developing the reflective sports coach: a study exploring the processes of reflective practice within a higher education coaching programme. *Reflective Practice*, 2(2), 185-207.

100. Knowles, Z, Gilbourne, D., Tomlinson, V. & Anderson A., G. (2007). Reflections on the application of reflective practice for supervision in applied sport psychology. *The Sport Psychologist*, *21*, 109-122.

101. Knowles, Z. Gilbourne, D., Cropley, B. & Dugdill, L. 2014. Reflective Practice in the Sport and Exercise Sciences. Contemporary Issues. Routledge, Abingdon, Oxon, UK. pp. 47-55.

102. Knowles, Z. email from the author. [Personal Communication: May 2016].

103. König, D., Northoff, H. & Berg, A. (2002). Factors triggering upper airway infections in athletes. *European Journal of Sport Science*, 2(4), 1-11.

104. Kolling, S, Steinacker, J., M., Endler, S., Ferrauti, A., Meyer, T. & Kellmann, M. (2016). The longer the better: sleep–wake patterns during preparation of the World Rowing Junior Championships. *Chronobiology International*, *33* 1: 73-84.

105. Kurosh Djafarian K., Speakman, J. R., Stewart, J. & Jackson, D., M. (2013). Comparison of activity levels measured by a wrist worn accelerometre and direct observation in young children. *Open Journal of Paediatrics,* 3, 422-427.

106. Kurt Kräuchi, K. & Wirz-Justice, A. (2001). Circadian Clues to Sleep Onset Mechanisms. N*europsychopharmacology*, 25, S92–S96.

107. Kushida, C. A., Chang A., Gadkary C., Guilleminault C., Carrillo O. & Dement W, C. (2001). Comparison of actigraphic, polysomnographic and subjective assessment of sleep parametres in sleep-disordered patients. *Sleep Medicine*, 2(5), 389-96.

108. Lambiase, M. J., Gabriel, K. P., Chang, Y. F., Kuller, L. H. & Matthews, K. A. (2014). Utility of Actiwatch Sleep Monitor to Assess Waking Movement Behaviour in Older Women. *Medicine & Science in Sports & Exercise*, published ahead of print.

109. Lastella M., Roach G. D., Hurem D. C. & Sargent C. (2010). Does chronotype affect elite athletes' capacity to cope with the training demands of elite triathlon? In: Sargent C, Darwent D., Roach G., D. (Eds). *Living in a 24/7 world: The impact of circadian disruption on sleep, work and health.* Australasian Chronobiology Society, Adelaide, Australia, 25-28.

110. Leeder, J., Glaister, M., Pizzoferro, K., Dawson, J. & Pedlar, C. (2012). Sleep duration and quality in elite athletes measured using wristwatch actigraphy. *Journal of Sports Sciences*, 30(6), 541–545.

111. Leger, D., Metlaine, A., Choudat, D. (2005). Insomnia and sleep disruption: relevance for athletic performance. *Clinicians in Sports Medicine*, 24(2), 269-85.

112. Leger D., Elbaz M., Raffray T., Metlaine, V., B. & Duforez, F. (2008). Sleep management and the performance of eight sailors in the Tour de France a la voile yacht race. *Journal of Sports Sciences,* 26(1), 21-8.

113. Lewandowski, A., S., Toliver-Sokol, M. & Palermo, T., M. (2011). Evidence-Based Review of Subjective Pediatric Sleep Measures, *Journal of Pediatric Psychology*, 36(7), 780–793.

114. Littlehales, N. (2012). Sleeping with the British Olympic Squad. [Online] Available from: http://sportsleepcoach.com. [Accessed February 2015].

115. Macora, S., M., Staiano, W & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology*. Volume 106(3), 857-864.

116. Mah, C. D., Mah, K. E., Kezirian, E. J. & Dement, W.C. (2011). The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep,* 34(7), 943-950.

117. Main, L, C. & Dawson, B. (2010). Relationship between Inflammatory Cytokines and Self-Report Measures of Training Overload. *Research in Sports Medicine*, 18, 127–139.

118. Males, J. (2012). *Onto the podium: What difference does 1% make?* [Online]. Significance magazine. Available from: http://www.significancemagazine.org [accessed February 2014].

119. Meeusen, R. Martine, D., Gleeson, M., Rietjens, G., Steinacker, J., & Urhausen, A. (2006). Prevention, diagnosis and treatment of the Overtraining Syndrome. *European Journal of Sports science* , 6(1), 1-14.

120. *(PDF) A review: managing jet lag - how to minimise the negative impact of extended travel on performance*. Available from: https://www.researchgate.net/publication/37357895_A_review_managing_jet_lag_-_how_to_minimise_the_negative_impact_of_extended_travel_on_performance [accessed Dec 11 2018].

121. Milewski, M. D., Skaggs, D. L., Bishop, G. A., Pace, J. L., Ibrahim, D. A., Wren, T. A., & Barzdukas, A. (2014). Chronic Lack of Sleep is Associated with Increased Sports Injuries in Adolescent Athletes. *Journal of Paediatric Orthopaedics,* 34(2), 129-133.

122. Milner C., E. & Cote, K., A. (2009). Benefits of napping in healthy adults: impact of nap length, time of day, age and experience with napping. *Journal of Sleep Research,* 18, 272-281.

123. Moraes, W., Poyares, D., Zalcman, I., de Mello, M.T., Bittencourt, L.R., Santos-Silva, R. & Tufik, S. (2013). Association between body mass index and sleep duration assessed by objective methods in a representative sample of the adult population. *Sleep Medicine,* 14(4), 312-8.

124. Morgan, K. (2013). Presentation. [Verbal communication: December 2013]. English Institute of Sport: 'Sleep and athletic performance' forum.

125. Morgan, K. (2016). Presentation. [Verbal communication: March 2016]. English Institute of Sport: 'Sleep to win' workshop.

126. Morgan, K. (2016). Semi structured interview. [Verbal communication: April 2016].

127. Morin, C., M. Vallières A; Ivers H. (2007). Dysfunctional Beliefs and Attitudes about Sleep (DBAS): Validation of a Brief Version (DBAS-16). *Sleep,* 30(11), 1547-1554.

128. Morton, J. (2009). Critical reflections from a neophyte lecturer in higher education: a self-narrative from an exercise physiologist. *Reflective Practice*, 10, 233-243.

129. Morton, J. In Knowles, Z., Gilbourne, D., Cropley, B & Dugdill, L. (2014). Reflective practice in the sport and exercise science. Contemporary issues. Routledge, Abingdon, Oxon, UK. pp. 124.

130. Morton, J. In Knowles, Z., Gilbourne, D., Cropley, B & Dugdill, L. (2014). Reflective practice in the sport and exercise science. Contemporary issues. Routledge, Abingdon, Oxon, UK. pp. 197.

131. Moser, D., Anderer, P., Gruber, G., Parapatics, S., Loretz, E., Boeck, M., Kloesch, G., Heller, E., Schmidt, A., Danker-Hopfe, H., Saletu, B., Zeitlhofer, J & Dorffner, G. (2008). Sleep classification according to AASM and Rechtschaffen & kales: Effects on sleeps coring parametres. *Sleep* (32), 139-149.

132. Murakami H, Kawakami R, Nakae S, Nakata, Y., Ishikawa-Takata, K., Tanaka, S., (2016). Accuracy of Wearable Devices for Estimating Total Energy Expenditure Comparison With Metabolic Chamber and Doubly Labeled Water Method. *JAMA International Medicine,* 176(5), 702–703.

133. Myllymaki, T., Kyrolainen, H., Savolainen, K., Hokka, L., Jakonen, R., Juuti, T., Martinmaki, K., Kaartinen, J., Kinnunen, M. & Rusko, H. (2011). Effects of vigorous late-night exercise on sleep quality and cardiac autonomic activity. *Journal of Sleep Research*, 20, 146-153.

134. Myllymäki. T. (2006). Heart Rate Variability – Based Recovery during Sleep Compared to Movement Analysis, Subjective Ratings and Cortisol Awakening Responses. Department of Biology of Physical Activity: University of Jyväskylä.. PhD Thesis.

135. Natale V, Plazzi G, Martoni M. (2009). Actigraphy in the assessment of insomnia: a quantitative approach. *Sleep,* 32(6), 767-71.

136. National Institute for Health and Care Excellence. (2015). Insomnia Guidelines [Online]. http://cks.nice.org.uk/insomnia#!references/-376579. [Accessed March 2016].

137. National Research Council Canada. (2018). Sport meets science: a winning combination. [Online]. https://www.nrc-cnrc.gc.ca/eng/stories/2018/sports_meet_science.html. [Accessed November 2018].

138. Nunn C.,L, Samson D.,R & Krystal A.,D. (2016). Shining evolutionary light on human sleep and sleep disorders. *Evolutionary Medicine in Public Health*, 3(1), 227-43.

139. The Oxford Dictionary [Online] www.oxforddictionaries.com [Accessed August 2016].

140. O'Donnell, S., Beaven, C. M., & Driller, M. (2018). The Influence of Match-Day Napping in Elite Female Netball Athletes. *International Journal of Sports Physiology and Performance,* 1-20.

141. Ohayon, M., Wickwire, E. M., Hirshkowitz, M., Albert, S. M., Avidan, A *et al.* (2017). National Sleep Foundation's sleep quality recommendations: first report. *Sleep Health*, 3, 6-19.

142. Partington, J., & Orlick, T. (1987). The sport psychology consultant evaluation form. *The Sport Psychologist*, 1, 309-317.

143. Patton, M. Q. (1990). Qualitative Evaluation and Research Methods (2nd ed.). Newbury Park, CA: Sage Publications, Inc.

144. Parnell, D., Ridgers, N. & Stratton, G. (2013) Learning from the experts: Exploring playground experience and activities using a write and draw technique. *Journal of Physical Activity & Health*, 10, 406-415.

145. Pieron, H. (1913). *Le problème physiologique du sommeil*. Masson, Paris, France.

146. Pilcher, J. J., Michalowski, K. R. & Carrigan, R. D. 2001. The Prevalence of Daytime Napping and Its Relationship to Nighttime Sleep. Behavioural Medicine. 27(2), 71-76.

147. Pilcher, J., J & Huffcutt, A., I. (1996) Effects of sleep deprivation on performance: a meta-analysis. *Sleep,* 19(4), 318-26.

148. Pipe A., L. (2011). International travel and the elite athlete. *Clinical Journal of Sports Medicine,* 21(1), 62-6.

149. Postolache, T, T. (2005). Sports Chronobiology. *Clinics in Sports Medicine,* 24, xix–xxii.

150. Pitchford N. W., Robertson, S. J., Sargent, C., Cordy, J., Bishop, D. J. & Bartlett, J., D. (2017). Change in Training Environment Alters Sleep Quality but Not Quantity in Elite Australian Rules Football Players. *International Journal of Sports Physiology and Performance,* 12(1), 75-78.

151. Postulouche, T. (2005). Sports Chronobiology. *Clinicians in Sports Medicine,* 24, xix-xxii.

152. Poussel M, Laroppe J, Hurdiel R, *et al.* (2015). Sleep Management Strategy and Performance in an Extreme Mountain Ultra-marathon. *Research in Sports Medicine: An International Journal*, 23(3), 1-7.

153. Prenderville, P. (2016). Analysing the reasons behind Team GB's success at Rio Olympics 2016. Sky Sports [Online]. Available from http://www.skysports.com/Olympics/news/15234/10548015/analysing-the-reasons-behind-team-gbs-success-at-rio-Olympics-2016. [Accessed 19th March 2018].

154. Rechtschaffen A, Kales A, eds. 1968. *A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects.* Los Angeles, CA: BI/BR.

155. Reid D., A. & McNair P., J. (2000). Factors contributing to low back pain in rowers. *British Journal of Sports Medicine,* 34,321–325.

156. Reilly, T & Edwards, B. (2007). Altered sleep-wake cycles and physical performance in athletes. *Physiology and Behaviour,* 90(2-3), 274-84.

157. Reilly, T. and Deykin, T. 1983. Effects of partial sleep loss on subjective states, psychomotor and physical performance tests. *Journal of Human Movement Studies*, 9, 157–170.

158. Riccio, D. (2014). Drifting off... Swimming Australia bans sleeping pills. The Daily Telegraph [Online], 23 March. Available from: http://www.dailytelegraph.com.au/news/nsw/drifting-off-swimming-australia-bans-sleeping-pills/story-fni0cx12-1226862017605?nk=14c81f891afc87664dadae4ece242e04. [Accessed February 2015].

159. Richmond, L. K., Dawson, B., Stewart, G., Cormack, S., Hillman, D. R., & Eastwood, P. R. (2007). The effect of interstate travel on the sleep patterns and performance of elite Australian Rules footballers. *Journal of Science and Medicine in Sport*, 10(4), 252-258.

160. Roach, G. D., Schmidt, W. F., Aughey, R. J., Bourdon, P. C., Soria, R., Claros, J. C. J., Sargent, C. (2013). The sleep of elite athletes at sea level and high altitude: a comparison of sea-level natives and high-altitude natives. *British Journal of Sports Medicine*, 47(1), i114–i120.

161. Routen, A. Letter form the Author. [Personal communication May 2014].

162. Saylor, C. R. (1990). Reflection and professional education: art, science and competency. *Nurse Adductor*, 15, 8-11.

163. Spry, T. (2001). Performing autoethnography: An embodied methodological praxis. *Qualitative inquiry*, *7*(6), 706-732.

164. Sadeh, A., & Acebo, C. (2002). The role of actigraphy in sleep medicine. *Sleep Medicine Reviews,* 6(2), 113–124.

165. Sadeh, A. (2011). The role and validity of actigraphy in sleep medicine an update. *Sleep Medicine Review*, 15(4), 259-267.

166. Sample, I. (2016). Sleep 'resets' brain connections crucial for memory and learning, study reveals. The Guardian [Online]. Available from: https://www.theguardian.com/science/2016/aug/23/sleep-resets-brain-connections-crucial-for-memory-and-learning-study-reveals [Accessed August 2016].

167. Samuels, C., H. (2008). Sleep, recovery, and performance: the new frontier in high-performance athletics. *Neurologic Clinics.* 26. 169–180.

168. Samuels, C., H. (2012). Jet lag and travel fatigue: a comprehensive management plan for sport medicine physicians and high-performance support teams. *Clinical Journal of Sports Medicine,* 22(3), 268-73.

169. Samuels C., H., James L, Lawson D & Meeuwisse, W. *(2016).* The Athlete Sleep Screening Questionnaire: a new tool for assessing and managing sleep in elite athletes. *British Journal of Sports Medicine,* 50, 418-422.

170. Sargent C., Schmidt W. F., Aughey R.J., Bourdon P.C., Soria R., Claros J.C., Garvican-Lewis L. A., Buchheit M., Simpson B. M., Hammond K., Kley M., Wachsmuth N., Gore C. J. & Roach G. D. (2013). The impact of altitude on the sleep of young elite soccer players (ISA3600). *British Journal of Sports Medicine*, 47, i86-92.

171. Sargent C., Lastella, M., Halson, S. & Roach, G., D. (2014a). The impact of training schedules on the sleep and fatigue of elite athletes. *Chronobiology International: The Journal of Biological & Medical Rhythm Research*, 31, 10, 1160-1168.

172. Sargent C., Halson, S. & Roach, G., D. (2014.b) Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers, *European Journal of Sport Science,* 14(1), 310-315.

173. Savis, J., C. (1994). Sleep and Athletic Performance: Overview and Implications for Sport Psychology. *The Sport Psychologist,* 8, 111-125.

174. Schaal, K., Le Meur, Y., Louis, J., Filliard, J. R., Hellard, P., Casazza, G., & Hausswirth, C (2015). Whole-body cryostimulation limits overreaching in elite synchronized swimmers. *Medicine & Science in Sports & Exercise* 47(7), 1416-1425.

175. Schwartz, J., R., L. & Roth, T. (2008). Neurophysiology of Sleep and Wakefulness: Basic Science and Clinical Implications. *Current Neuropharmacology*, 6, 367-378.

176. Shahid, A., Wilkinson, K., Marcu, Shai. and Shapiro, C., M. (2012). Dysfunctional Beliefs and Attitudes about Sleep Scale (DBAS). Stop That and One Hundred Other Sleep Scales. Springer New York. New York, NY.

177. Shapiro, C.M., R. Bortz, D. Mitchell, P. Bartel, and P. Jooste. (1981). Slow-wave sleep: a recovery period after exercise. *Science,* 214,1253-1254.

178. Silber, M. H., Ancoli-Israel S., Bonnet, M. H., Chokroverty, S., Grigg-Damberger,M., Hirshkowitz, M., Kapen, S., A Keenan, S., Kryger, M., Penzel, T., R Pressman, M., Iber,C. (2007). The visual scoring of sleep in adults. *Journal of Clinical Sleep Medicine,* 3(2), 121-131.

179. Silva, A., Queiroz, S, S., Winckler, C., Vital, R., Sousa, R, A., Fagundes, V., Tufik, S. & de Mello, M, T. (2012). Sleep quality evaluation, chronotype, sleepiness and anxiety of Paralympic Brazilian athletes: Beijing 2008 Paralympic Games. *British Journal of Sports Medicine*, 46(2), 150-154.

180. Silva, M. & Paiva, T. (2013). Sleep, precompetitive stress and achievements in young performance athletes. *Sleep Medicine*, 14(1), e269.

181.Sinnerton, S. A. & Reilly, T. (1992). Effects of sleep loss and time of day in swimmers. In D. MacLaren, T. Reilly & A. Lees (Hrsg.), *Biomechanics and Medicine in Swimming. Swimming Science VI* (, S. 399-404). London: E & FN Spon.

182. Skein, M., Duffield, R., Edge, J., Short, M, J. & Mündel, T. (2011). Intermittent-sport performance and muscle glycogen after 30 h of sleep deprivation. *Medicine and Science in Sport and Exercise,* 43(7), 1301 – 1311.

183. Smith, D, J. (2003). A framework for understanding the training process leading to elite performance. *Sports Medicine,* 33 (15), 1103-1126.

184. Smith, T. B., Hopkins, W. G. & Lowe, T. E. (2011). Are There Useful Physiological or Psychological Markers for Monitoring Overload Training in Elite Rowers? *International Journal of Sports Physiology and Performance,* 6, 469-484.

185. Spencer, M., B. & Montgomery J., M. (1997). Sleep patterns of aircrew on charter/air haulage routes. PLSD Report No PSLD CHS5/CR/96/082). Hampshire: Defence Evaluation Research Agency.

186. Spiegel halder, K., Fuchs, L., Ladwig, J., Kyle, S.D., Nissen, C., Voderholzer, U., Feige, B. & Riemann, D. (2011). Heart rate and heart rate variability in subjectively reported insomnia. *Journal of Sleep Research*, 20, 137-145.

187. Swann, C., Moran, A., & Piggott, D. (2015). Defining elite athletes: issues in the study of expert performance in sport psychology. *Psychology of Sport and Exercise*, 16 (1), 3-14.

190. Sperlich, B., Becker, M., Hotho, A., Wallmann-Sperlich, B., Sareban, M., Winkert, K., Steinacker, J and Treff, G. (2017). Sedentary Behaviour among National Elite Rowers during Off-Training—A Pilot Study. *Frontiers in Physiology,* 8, 655.

191.Takahashi, Y., Kipnis D., M & Daughaday W., H. (1968). Growth hormone secretion during sleep. The *Journal of Clinical Investigation*, 47, 2079-2090.

192. Taylor, S.R., Rogers, G.G. & Driver, H.S., (1997). Effects of training volume on sleep, psychological, and selected physiological profiles of elite female swimmers. *Medicine and Science in Sports and Exercise*, 29(5),688-693.

193. Tedlock B. (1991). From Participant Observation to the Observation of Participation: The Emergence of Narrative Ethnography*. Journal of Anthropological Research*, 47(1), 69-94.

194. Telos Partners LLP (2007). Presentation on a management course [Personal communication: 2007].

195. The Oxford Dictionary. (2017). [Online]. Available from https://en.oxforddictionaries.com/definition/ontology [Accessed 10 October 2014].

196. Thomas J.R. & Nelson, J.K (1996). Research Methods in Physical Activity. Human Kinetics Publishers, Champaigne, IL, USA.

197. Thompson, K. G. (2010). Being an elite sports scientist: a balancing act? *International Journal of Sports Physiology and Performance,* 5, 12.

198. Thornton, H., Duthie, G. M., Pitchford, N., Delaney, J. A., Benton, D. T., Dascombe, B. J. (2016). Effects of a Two-week High Intensity Training Camp on Sleep Activity of Professional Rugby League Athletes. International Journal of Sports Physiology and Performance, 1-19.

202. Thun, E., Bjorvatn, B., Flo, E., Harris, A. & Pallesen,S, (2015). Sleep, circadian rhythms, and athletic performance. *Sleep Medicine Reviews*, 23, 1-9.

203. Trost, S., G. (2007). State of the art reviews: Measurement of physical activity in children and adolescents. *American Journal of Lifestyle Medicine*, 1(4), 299–314.

204. Tryon, W., W. (2004). Issues of Validity in Actigraphic Sleep Assessment. *Sleep,* 27(1), 158–165

205. Trek, F. Presentation. [Verbal communication: May 2013]. American College of Sports Medicine Annual Meeting.

206. Tuomilehto, H., Vuorinen, V.,P., Penttilä, E., Kivimäki, M., Vuorenmaa, M., Venojärvi, M., Airaksinen, O. and Pihlajamäki, J. (2016) Sleep of professional athletes: Underexploited potential to improve health and performance. *Journal of Sports science s*, 13, 1-7.

207. Uzat (1998) in Farro (2000) Reflective Practice and Professional Development. [Online]. Available from http://searcheric.org/digests/ed449120.html [Accessed August 2014].

208. UK Sport. (2017). [Online]. Available from http://www.uksport.gov.uk/our-work/investing-in-sport. [Accessed November 2017].

209. Van Cutsem, J., Marcora, S., De Pauw, K. Bailey, S., Meeusen, R. & Roelands, B. (2017). The Effects of Mental Fatigue on Physical Performance: A Systematic Review. *Sports Medicine,* 47(8), 1569-1588.

210. Venter, R. E., Potfeiter, J. T. & Barnard, J. G. (2010). The use of recovery modalities by elite South African team athletes. South African Journal for Research in Sport, Physical Education and Recreation. 32(1), 133-145.

211. Venter, R., E. 2012. Role of sleep in performance and recovery of athletes: a review article. *South African Journal for Research in Sport, Physical Education and Recreation,* (31). 167-164.

212. Wall, S. P., Mattacola, C. G., Swanik, C. B. & Levenstein, S. (2003). Sleep efficiency and overreaching in swimmers. *Sport Rehabilitation,* 12, 1-12.

213. Wallop, H. 2014. Are you getting enough sleep? The Telegraph [Online], 14 May. Available from: http://www.telegraph.co.uk/news/health/news/10827613/Are-you-getting-enough-sleep.html. [Accessed February 2015].

214. Waterhouse, J., Edwards, B., Nevill, A., Atkinson, G., Reilly, T., Davies, P., & Godfrey, R. (2000). Do subjective symptoms predict our perception of jet-lag? *Ergonomics,* 43(10), 1514-1527.

215. Waterhouse, J., Reilly, T., Atkinson, G. & Edwards, B. (2007). Jet lag: trends and coping strategies. *The Lancet* 369(9567), 1117-29.

216. Waterhouse, J., Reilly, T., & Edwards, B. (2004). The stress of travel. *Journal of Sports Sciences*, 22, 946–966.

217. Weiler, R., Aggio, D., Hamer, M., Taylor, T., & Kumar, B. (2015). Sedentary behaviour among elite professional footballers: health and performance implications. *British Journal of Sports Medicine. Open Sport and Exercise Medicine,* 1.

218. Winget, C. M., DeRoshia, C. W., & Holley, D. C. (1985). Circadian rhythms and athletic performance. *Medicine and Science in Sports and Exercise*, 17, 498–516.

219. Winter E., M. & Maughan R., J. (2009). Requirements for ethics approvals. *Journal of Sports Sciences,* 27(10), 985-985.

220. Xie, L., Kang, H., Xu, Q., Chen, M. J., Liao, Y., Thiyagarajan, M., O'Donnell, J., Christiansen, D., J., Nicholson, C., Iliff, J., J., Takano, T., Rashid, D. & Nedergaard, M. (2013). Sleep Drives Metabolite Clearance from the Adult Brain. *Science,* 18(342), 1241-224.

221. Zhao, J., Tian, Y., Nie, J., Xu, J. & Liu, D. (2012). Red light and the sleep quality and endurance performance of Chinese female basketball players. *Journal of Athletic Training*, 47(6), 673 – 678.

Appendices

Appendix 1

- Informed Consent forms: University of Kent & English Institute of Sport

- Letter to interviewee's

- Ethics forms

PHYSIOLOGY CONSENT FORM – CONFIDENTIAL

ENGLISH INSTITUTE OF SPORT

Assessment date & time: **Assessment location:**

I (print name) ………………………………………………. consent to participating in this assessment on the following terms:

1. I have had the assessment procedures verbally explained to me and understand what I will be required to do.

2. I understand that (if required by the assessment procedures) I will be undertaking physical exercise at or near the extent of my capacity and that there is possible risk in the physical exercise at that level, that is, episodes of transient light headedness, fainting, abnormal blood pressure, chest discomfort, and nausea. I understand that this may occur though the EIS Scientists will take all proper care in the conduct of the assessment and I will fully assume that risk.

3. I am aware of the possible dangers of certain blood borne diseases (HIV, Hepatitis B) associated with blood sampling and understand that the EIS Scientists will take all proper care in the conduct of the blood sampling.

4. I understand that I can withdraw myself from any of the assessments at any time.

5. I have told the scientists conducting the assessment about any illness or physical defect I have that may contribute to the level of that risk.

6. I hereby release the EIS, this facility and the EIS service provider from any liability for any injury or illness that I may suffer while undertaking the assessments, or subsequently occurring in connection with the assessments or that is to any extent contributed to by it, other than in respect of death or personal injury arising from those parties' negligence.

7. I will indemnify this facility and the EIS with respect to any liability it may incur in relation to any other person in connection with the assessment to the extent permissible by law.

8. I hereby agree that I am in a suitable condition for physiological assessment having abided by the requirement for diet and activity prescribed for me by the service provider and/or as directed by my NGB.

9. I understand that data collected as part of any assessment maybe used for future publication in external outlets for the furtherance of science. I understand this data will be anonymised.

Signed: ……………………………………………… Date: ……………………………….
(Parent or Guardian if athlete Under 16)

Witness: ……………………………………………… Date: ……………………………….

Sarah Gilchrist

EIS Bisham
The Performance Centre
Bisham Abbey NTC
Nr Marlow
Bucks
SL7 1RR

Tel: 07930 574059

[date]

[Participant name]

[Participant address]

Dear [name],

Re. Professional Doctorate Research

Further to prior discussions I am writing to you in my capacity as a full time senior practitioner with the English Institute of Sport (EIS). As part of which I am studying towards my professional doctorate in sport and exercise science at the University of Kent, supervised by Professor Louis Passfield.

My research proposal is outlined below, however in order to provide some context to my thesis I need to conceptualise the UK Sport system through interviewing key professionals who have been involved in the organisation and within the industry as a whole. You have been identified as one of these individuals in the hope you will participate in a face to face interview at your convenience.

Research Proposal:
The determinants of performance in Olympic rowing and the benefit of describing sleep and daytime activity & rest profiles as contributing factors to such determinants

The specific purpose of the interview is to help me establish details for my professional doctorate with regard to the philosophy and intent behind the establishment of the UK Sport system. Principally I'm interested in the period 2000-2012 but there will be opportunity in the interview to elaborate on any aspect of your involvement with UK Sport.
The interview will take approximately 60-90 minutes. There are seven sections focusing on your involvement in UK Sport, the evolution of the system and the challenges faced. There is a final section focused on evaluating the process you went through during your involvement with UK Sport.

The entire process will be completely confidential and you have the right not to answer any questions or withdraw without an explanation needed as per your participant information/consent form (see attached).

The intention is to record the interview using a Dictaphone and the recordings will be transcribed by me (lead researcher) and saved on my EIS encrypted laptop with the raw files deleted. Data will be analysed and categorised into 'themes' for analysis. The data will remain part of the professional doctorate thesis with the opportunity for future publication. Should you request it you will have the opportunity to review the results based on your input.

I will be contacting you in the next few days to confirm your consent and availability for the interviews and if so, to arrange a mutually convenient time and place to conduct them.

In the meantime if you have any further queries please do not hesitate to contact me on the enclosed details.

Yours sincerely,

Sarah Gilchrist BASES HPSA, CSci | Senior Physiologist, Technical Lead | GB Rowing Team
English Institute of Sport

CONSENT FORM

University of Kent

Title of project:

Name of investigator:

Participant Identification Number for this project:

Please initial box

1. I confirm I have read and understand the information sheet dated… (version…) for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. *(Insert contact number here of lead researcher/member of research team, as appropriate).*

3. I understand interviews will be recorded and I consent to audio recording of interviews.

4. I understand that my responses will be anonymised before analysis. I give permission for members of the research team to have access to my anonymised responses. *(Also add here a statement about publication of anonymised direct quotes, if this will be done).*

5. I agree to take part in the above research project.

Name of participant	Date	Signature
Name of person taking consent *(if different from lead researcher)* *To be signed and dated in presence of the participant*	Date	Signature
Lead researcher	Date	Signature

Copies: *When completed: 1 for participant; 1 for researcher site file; 1 (original) to be kept in main file*

ETHICS REVIEW CHECKLIST FOR RESEARCH WITH HUMAN PARTICIPANTS – FACULTY OF SCIENCES

University of Kent

A checklist should be completed for every research project in order to identify whether a full application for ethics approval needs to be submitted.

The principal investigator or, where the principal investigator is a student, the supervisor, is responsible for exercising appropriate professional judgement in this review.

This checklist must be completed before potential participants are approached to take part in any research.

All forms must be signed by the School's Research Ethics Advisory Group representative.

Section I: Project details	
Project title:	The determinants of performance in Olympic rowing and the benefit of describing sleep and daytime activity & rest profiles as contributing factors to such determinants
Planned start date: 1st September 2014	Planned end date: 1st August 2019
Funder:	English Institute of Sport

Section II: Applicant details	
Applicant name:	Sarah Gilchrist
Department:	Faculty of Sciences
Email: sarah.gilchrist@eis2win.co.uk	Telephone number: 07930 574059
Contact address:	EIS Bisham The Performance Centre Bisham Abbey NTC Nr Marlow Bucks SL7 1RR

Applicant signature:	S Gilchrist	**Date**	1.7.14

Section III: Students only				
Supervisor:				
Undergrad. ☐	Postgrad ☐	Masters ☐	Doctorate ✓	Other (please specify)

Supervisor signature:	Louis Passfield	**Date**	1.7.14

School REAG rep signature:		**Date**	

If all questions in the checklist are answered as 'no', **send the completed and signed form to the School office (r.e.cox@kent.ac.uk), with any further required documents, for their records.**

If any question in Section IV(A) are answered 'yes', **you will need to send the completed form to the School office (r.e.cox@kent.ac.uk) for reference and submit your research for ethics approval to the appropriate body. For advice and assistance with this process please contact the Research Ethics & Governance Officer.** Once ethical approval is granted, a copy should be sent to the Faculties Support Office for their records.

If any questions in Section IV(B) are answered 'yes', **you will need to complete the full application form and send it to the School office (r.e.cox@kent.ac.uk) for review by the School of Sport & Exercise Sciences Research Ethics Advisory Group (REAG) along with a copy of the project proposal form and any supporting documentation such as patient information sheets and consent forms.**

Please note that it is your responsibility to follow, and to ensure that all researchers involved with your project follow, accepted ethical practice and appropriate professional ethical guidelines in the conduct of your study. You must take all reasonable steps to protect the dignity, rights, safety and well-being of participants. This includes providing participants with appropriate information sheets, ensuring informed consent and ensuring confidentiality in the storage and use of data.

Any significant change in the question, design or conduct over the course of the research should be notified to the School office (r.e.cox@kent.ac.uk) and may require a new application for ethics approval.

Section IV: Research Checklist

Please answer all questions by ticking the appropriate box:

A) Research that may need to be reviewed by an NHS Research Ethics Committee, the Social Care Research Ethics Committee (SCREC) or other external ethics committee (if *yes*, please give brief details as an annex)	**YES**	**NO**
Will the study involve recruitment of patients through the NHS or the use of NHS patient data or samples?	☐	✓
Will the study involve the collection of tissue samples (including blood, saliva, urine, etc.) from participants or the use of existing samples?	☐	✓
Will the study involve participants, or their data, from adult social care, including home care, or residents from a residential or nursing care home?	☐	✓
Will the study involve research participants identified because of their status as relatives or carers of past or present users of these services?	☐	✓
Does the study involve participants aged 16 or over who are unable to give informed consent (e.g. people with learning disabilities or dementia)?	☐	✓
Is the research a social care study funded by the Department of Health?	☐	✓
Is the research a health-related study involving prisoners?	☐	✓

If the answer to any questions in Section IV A is 'yes', please contact the Research Ethics & Governance Officer for further advice and assistance.

B) Research that may need full review by the Sciences REAG	**YES**	**NO**
Does the research involve other vulnerable groups: children; those with cognitive impairment; or those in unequal relationships, e.g. your own students?	☐	✓
Does the project involve the collection of material that could be considered of a sensitive, personal, biographical, medical, psychological, social or physiological nature, other than one that is covered by existing block approval?	☐	✓
Will the study require the cooperation of a gatekeeper for initial access to the groups or individuals to be recruited (e.g. students at school; members of a self-help group)?	☐	✓
Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g. covert observation of people in non-public places?)	☐	✓

Will the study involve discussion of sensitive topics (e.g. sexual activity; drug use; criminal activity)?	☐	✓
Are drugs, placebos or other substances (e.g. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	☐	✓
Is pain or more than mild discomfort likely to result from the study?	☐	✓
Could the study induce psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life?	☐	✓
Will the study involve prolonged or repetitive testing?	☐	✓
Will the research involve administrative or secure data that requires permission from the appropriate authorities before use?	☐	✓
Is there a possibility that the safety of the researcher may be in question (e.g. international research; locally employed research assistants)?	☐	✓
Does the research involve members of the public in a research capacity (participant research)?	☐	✓
Will the research take place outside the UK?	☐	✓
Will the outcome of the research allow respondents to be identified either directly or indirectly (e.g. through aggregating separate data sources gathered from the internet)?	☐	✓
Will research involve the sharing of data or confidential information beyond the initial consent given?	☐	✓
Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?	☐	✓
Will the proposed findings be controversial or are there any conflicts of interest?	☐	✓

Appendix 2

- Interview Guide

<u>Interview Guide</u>

Project Name:

The introduction and impact of sleep and movement behaviour (defined by daytime 'rest and activity' profiles) assessment in high performance athletes

Interview Number:

Interview ID: ***first 3 letters of surname and date e.g. *** mmyy***

Current Occupation and in post since

Interviewer:

Date of interview:

Part and Aim	**Questions**
Part 1: Introduction **Aim:** **Explain the importance and explanations about this interview (expected time, aims, interview structure and reinforce confidentiality)**	Hi '......' Thanks for meeting me today. You have been selected as a key person to interview through your contact with a project involving sleep and/or movement behaviour. Therefore you are ideally suited to help ascertain the details behind the introduction of sleep and movement behaviour (defined by daytime 'rest and activity' profiles) assessment to the UK high performance sport system. I'd just like to reiterate this process is completely confidential and you have the right not to answer any questions or withdraw without an explanation needed as per your participant information/consent form. Just to state I'll be recording this interview using a Dictaphone and the recordings will be transcribed by me and saved on my encrypted laptop with the raw files deleted. **Aim** The purpose of the interview is to help me explore impact of the introduction of the assessment of sleep and movement behaviour of high performance athletes. Principally I'm interested in the period 2010-2016 but please feel free to elaborate on any aspect of your involvement although please state any periods of time you're referring to. I'm particularly interested in two areas: firstly **<u>if</u>** and **<u>what</u>** you feel have been are the key differences the introduction of sleep and movement behaviour has made to the Sports Science and Medicine support services provided to high performance athletes. Secondly I'm interested in your opinion as to the new 'area' in sports science (sleep) being used to assessed to help athletes perform better.

	The interview will take approximately 1 hour. There are five sections; Section one is this part, introducing the interview and what it entails for both you and I. Section two is about focusing on the concept behind analysing sleep and movement behaviour in high performance sport and to establish your involvement in the process of introducing sleep and activity analysis to high performance sport. Section three aims to track your understanding of the introduction of sleep and movement behaviour into high performance sport and any perceived impact it may have had. It also serves to allow you to offer any challenges that you may have faced. There is a further section whereby your evaluation of the process of introducing sleep and activity analysis to the high performance sport industry would be welcomed and any reflections you might have as to what could have been done differently. Your insights here may well inform future directions as to where research can be targeted in the next Olympic cycle. Finally there is a summary section to clarify any points made during the interview and for you to ask me any questions you may have about what we have discussed and offer a comment on how the interview process was for you. Having provided you with all this information can you please state for the record you are happy to proceed with the interview?

Part 2: Background Information **Aims:** **Gain background information and involvement in sleep and activity assessment.** **Establish the concept behind analysing sleep and activity in high performance sport.** **Establish interviewee's involvement in the process of introducing sleep and activity analysis to high performance sport.**	Briefly tell about what your current role entails? Can you explain to me how you began working in the area of sleep research/support to athletes'. Or How does the area of sleep research/support to athletes' fit into your daily role? How have you contributed directly or indirectly, to the development of sleep and movement behaviour within high performance sport? In your own words what do you see as the basis for the concept behind introducing sleep and movement behaviour of high performance athletes to the UK sports system? **When** did you become aware the assessment of sleep and movement behaviour in high performance athletes was being conducted and developed? **How** did you become aware the concept of assessment of sleep and movement behaviour in high performance athletes was being conducted and developed? In your own words can you explain **why** you think it's important that sleep and movement behaviour analysis are part of a support package that high performance athletes would receive? **What** do you feel are the benefits of developing analysis of sleep and movement behaviour within high performance sport? **What** do you feel are the disadvantages of developing analysis of sleep and movement behaviour within high performance sport?

Part 3: Evolution **Aims:** **Identify the evolution of introducing the concept of sleep and activity analysis to high performance sport and the impact it has had.** **Identifying any challenges faced.**	OK so I'd now like to move on to explore the evolution of introducing the concept of sleep and activity analysis to high performance sport and the impact it has had. For all of the questions in this section I'd like to hear about your direct involvement and any generic comments you may have. Please can you describe the evolution of introducing the concept of sleep and movement behaviour analysis to high performance sport? Are you aware of the knowledge 'outlets' that have been conducted on the topic of sleep and movement behaviour analysis? How has the dissemination of knowledge about sleep in particular and athletic performance been achieved? Currently how much general knowledge do you think here is about the topic in the UK high performance sport system. Can you provide examples of athletes' knowledge (or lack of) about sleep and movement behaviour? Describe in your own words how you feel sleep and movement behaviour analysis have benefited athletes in the UK high performance sport system? Can you comment on the impact it has had to athletes? Has this made a difference to practitioner delivery? Or Based on your experiences of sleep and movement behaviour analysis in high performance sport do you think we could have done anything better to implement what we have to date? Has introducing the concept of sleep and movement behaviour analysis to high performance sport been successful? If so, what have been critical factors to this success? Or Has introducing the concept of sleep and movement behaviour analysis to high performance sport made a difference to athletes and their ability to perform in training and competition? What has made the difference?

	What do you believe are the challenges to practitioners delivering good sleep and movement behaviour analysis to high performance athletes? What do you think are the challenges to getting high performance athletes and coaches to understand the importance of good sleep? What are the challenges to getting high performance athletes and coaches to understand the importance of good 'downtime'? Have, in your opinion, these been overcome? How? Could you also describe any challenges faced in the process of establishing sleep and activity analysis in high performance sport? What are the outstanding challenges that remain? Can you identify what you feel is the key challenge? What limitations are there to educating athletes about sleep and athletic performance?

Part 4: Evaluation and future directions **Aims:** **To evaluate the process and establish what could have been done differently** **To establish any future directions and where research can be targeted in the next Olympic cycle.**	Since London 2012 there has been an immense amount of work delivered in the field sleep and movement behaviour analysis to UK sport athletes. Has this been a success for the EIS practitioners involved? What is the context here, is it in their opinion or that of EIS for example? Is there anything you would have done differently? In the next Olympic cycle it is thought that there will be further challenges from funding agencies, where do you think the next key strategic move will be in progressing the area of sleep and athletic performance? I wonder if they even see it as a priority and why? Might be reiterating the same point here as above but useful to test their statements also If you were in my position are there any other channels of enquiry that you would investigate?
Part 5 End of Interview **Aim:** **Clarification and appreciation of participant time and knowledge**	That concludes the interview. Thank you very much for your insight, opinions and time today. The transcript will be available to you should you wish to read it and of course any finding from the study will be made available to you should you request it.

Appendix 3

- EIS Forum submission 2013
- ACSM presentation 2013
- EIS Sleep Workshop 2014
- EIS Sleep Roadshow 2016

SLEEP FORUM 2011

EIS National Conference: Forum Submission

Forum Title: Sleep and Athletic Performance: A Multidisciplinary Perspective

Sleep plays an important part in the body's biological and physiological processes for rest, recovery and adaptation. In elite athletes, sleep and recovery between training bouts are paramount for optimising delivery of performance in training and competition.

Sleep quality and structure among elite athletes is challenged by the physiological stress of training, the emotional stress of competing, and the circadian demands of integrating training programmes into school, university and family life. Concerns over poor sleep quotas in the athletic population stem from the knowledge that despite individual requirements for sleep displaying large variations, chronic reduction in sleep can lead to immuno-suppression (Reilly & Edwards, 2007)**.**

Sleep and athletic performance have developed interest in the popular and academic literature over recent years. Anecdotal and limited empirical evidence indicates that athletes, as a group, experience degraded sleep quality relative to age-matched non-athlete controls (e.g. Leeder *et al.*, 2012), and that this sleep disruption is amplified during and immediately after competitions (Erlacher *et al.*, 2011).

Conversely, emerging (but un-replicated) evidence suggests that improved sleep quality can enhance individual (Mah *et al.*, 2011; Skein *et al.*, 2011) and team (Zhao *et al.*, 2012) athletic performance. However, the robustness of, and possible mechanisms mediating these effects remain unknown. In addition, the nature and effectiveness of sleep management strategies to maintain performance following circadian challenge remain either undeveloped, or untested.

To date, some EIS Practitioners have proactively surveyed sleep characteristics and the application of 'downtime' within Olympic and Paralympic Sports. This session aims to describe and educate multi-disciplinary practitioners as to the principle areas of interest for sleep and athletic performance from physiological, psychological and nutritional examples. Further, we aim to develop awareness of the technologies available to analyse elite athletes' sleep and update the audience on current work within the institute. The expectation being this will enhance the impact we have as a network of multidisciplinary practitioners on sleep and performance, through gaining consistency of message, collaboration and quality assured practice, coupled with development of technology utilised.

Speakers:

Professor Kevin Morgan - Loughborough University

Sarah Gilchrist Luke Gupta, Dan Kings – English Institute of Sport

Biographies:

Professor Kevin Morgan Kevin Morgan is Professor of Psychology and Director of the Clinical Sleep Research Unit in the School of Sport, Exercise and Health Sciences, Loughborough University. Specialising in the origins, impact and treatment of insomnia-type sleep disorders his research includes the development of cognitive-behavioural approaches to sleep management and the impact of physical activity on sleep quality. His publications include over 150 scientific papers and several books (including the seminal Sleep and Aging, Johns Hopkins University Press, 1987). He is a Member Academician of the Academy of Social Sciences, an associate Fellow of the BPS, has served as an advisor to the UK Medicines and Healthcare Products Regulatory Agency (MHRA) and National Institute for Health and Clinical Excellence, and is an Associate Editor of *Behavioral Sleep Medicine*.

Sarah Gilchrist After qualifying with her MSc in Exercise Physiology, Sarah worked for seven years at the Welsh Institute of Sport working with Olympic and Paralympic Sports. She provided physiological support at the Commonwealth Games 2002, 2006 and to GB Badminton for Athens 2004. She moved to work with the GB Rowing Team at the EIS in January 2007 and is now the physiology technical lead at EIS Bisham. In addition to front line service delivery to the GB Rowing Olympic and Paralympic teams, Sarah manages the staff and resources in the physiology facility at Bisham Abbey. She has as specific interest in the area of sleep an athletic performance and in simulating environmental conditions through the environmental chamber at Bisham Abbey.

Luke Gupta Luke graduated from the University of Bath in 2009 with a BSc in Sport and Exercise Science. During this time he completed a placement year at Tottenham Hotspur Football Club before undertaking an Exercise Physiology MSc at Loughborough University. During his MSc he completed an internship with the Loughborough Sport Science Service. After graduating his MSc he completed a work placement with British Swimming before joining the EIS Talent Team as an intern. On completion of the internship he took on the role of Sport Science Technician (Physiology) for both the EIS Bisham and Manchester laboratories. In his current role, he is conducting a PhD Studentship into Sleep and Athletic Performance alongside duties as the Sport Science Technician within the EIS Bisham laboratory.

Lead Individual:

Sarah Gilchrist

EIS Bisham

Sarah.gilchrist@eis2win.co.uk

+44 (0)7930 574059

References

Reilly T, Edwards B, 2007. Altered sleep-wake cycles and physical performance in athletes. Physiol Behav.Feb 28;90(2-3):274-84. Epub 2006 Oct 25.

http://www.ncbi.nlm.nih.gov/pubmed/17067642

Sleep Characteristics and Quality from Domestic and Overseas Training Environments in Paralympic Rowers

Sarah L. Hardman[1], Stephen A. Ingham[2].
[1]*English Institute of Sport , Marlow, United Kingdom.*
[2]*English Institute of Sport , Loughborough, United Kingdom.*

Purpose

This study analyses the sleep characteristics of an international Paralympic rowing squad in domestic and overseas training environments in Paralympic Year.

Introduction

•The drive to sleep is an important and insistent physiological function, without which basic physiological function is compromised.

•A link between critical sleep factors, cognitive processes and metabolic function is evident (Samuels 2008).

•To optimise athletic training and performance recovery is essential to restore and allow adaptation.

•Sleep is the primary opportunity and wakeful rest the secondary opportunity for restorative process to take place for elite athletes.

•Research has shown that athletes have poorer markers of sleep quality than age and sex matched controls (Leeder et al).

•Rowing training is high in volume and involves several overseas training camps.

•Sleep characteristics of the GB Rowing Team in the domestic environment was compared that of and overseas sea level training camp.

Methods

•Two female and two male competitive adaptive rowers, age 27 ± 3.3 yr; body mass 78.0 ± 11.2 kg; stature 1.82 ± 5.5 m, in rowing categories of ASx and LTA4[+] participated in this investigation.

•Sleep characteristics were assessed in both a domestic (UK) environment (HOME) and at an overseas (Spain) sea-level training camp (CAMP), using non-dominant wrist actigraphy (Actiwatch AW2, Philips Healthcare, UK).

•Sleep at the overseas camp was recorded from day two to allow for travel transition and time zone shift (1 hour).

•Sleep structure was assessed by discriminating; time to bed, time in bed, get up time, time asleep, sleep latency. Sleep quality was determined as; sleep efficiency and fragmentation index (derived from Actiwatch software algorithm). Self reported quality of sleep was recorded during assessment periods as a percentage. Definitions of sleep markers assessed our outlined in Table 1.

Table 1. Definitions of sleep variables assessed using wrist actigraphy

Variable	Definition
Time to bed (hrs:mins)	Inputted bed time as defined by the athlete
Time in bed (hrs:mins)	The difference between the get up and bed time as defined by the athlete
Get up time (hrs:mins)	Inputted get up time as defined by the athlete
Time asleep (hrs:mins)	The amount of sleep as determined by the actiwatch algorithm and is equivalent to assumed sleep minus wake time
Sleep latency (hrs:mins)	The latency period before sleep onset following bed time
Sleep Efficiency (%)	The percentage of time spent asleep whilst in bed
Fragmentation index	A measure of restlessness during sleep using the percentage of epochs where activity is >0 (Leeder et al 2012)

Results

•Time to bed (start time) was later (P = 0.047) at HOME compared to CAMP (22:37 ± 0.03 vs. 22:17 ± 0.02) (Figure 1).

•Get up time (end time) at HOME was later (P < 0.05) than CAMP, (06:57 ± 0.04 vs. 06:06 ±0.02). There was a trend toward a greater time in bed at HOME compared to CAMP (8.3 ± 1.0 vs. 7.8 ± 0.8 hr, P = 0.06). (Figure 2)

•Actual sleep time (6.9 ± 1.0 vs. 6.7 ± 0.9 hr), sleep latency (26.4 ± 13.3 vs. 24.8 ± 15.1 min), sleep efficiency (78.5 ± 9.4 vs. 79.0 ± 8.6 %) and fragmentation index (30.1 ± 10.2 vs. 28.4 ± 13.4) were not different between conditions for HOME and CAMP respectively. (Figure 2 and 3)

•Self reported quality of sleep was greater (P <0.01) for HOME (91 ± 10.6 %) versus CAMP (85 ± 15.1 %).

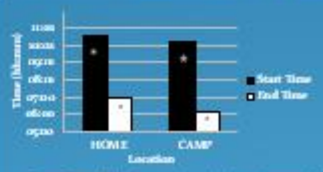


Figure 1 Time to bed and get up time of paralympic rowers at HOME and CAMP (*P = <0.05)

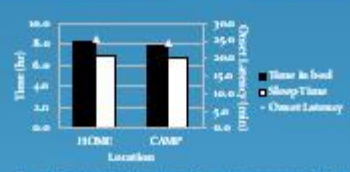


Figure 2 Time in bed and time asleep of paralympic rowers at HOME v CAMP

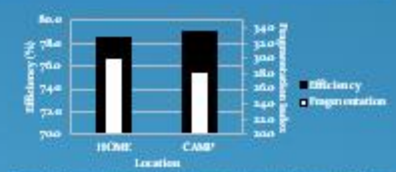


Figure 3 Markers of sleep quality (efficiency and fragmentation index) of elite rowers

Summary & Conclusions

•Results suggest sleep structure, as indicated by time to bed, get up time, and a tendency for greater time in bed, is different between HOME and CAMP environments.

•Objective measurements of sleep quality suggest no differences, however subjective reports indicate better sleep at HOME compared to CAMP.

•The study allowed greater multidisciplinary team working to proactively identify interventions for improved sleep hygiene. Further it helped negate the culture of pharmacological interventions for improving sleep before addressing poor sleep strategies.

References
Samuels, C. 2008. Sleep, Recovery and Performance: The New Frontier in High Performance Athletics. Neurol Clin 26, 169-180

Leeder, J., Glaister, M., Pizzoferro, K., Dawson, J. & Pedlar, C. 2012. Sleep duration and quality in elite athletes measured using wristwatch actigraphy. Journal of Sports Sciences, 1-2

ENGLISH INSTITUTE OF SPORT

GBROWINGTEAM

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PHILIPS RESPIRONICS

EIS Sleep workshop 2014

EIS Physiology CPD Series: Workshop for practitioners

Speakers:

Sarah Gilchrist EIS Technical Lead Physiologist

Luke Gupta, EIS PhD Student

Location:

EIS Bisham, 28th August 2014

Objectives and outcomes

- To provide:
    - context to the new area of expertise: 'sleep and athletic performance'
    - a broad overview of current research in the domain of 'sleep and athletic performance' (e.g. why it's important, what's missing)
    - practical examples and models of optmal practice for analysing athletes sleep and movement behaviour
    - an applied focus to research projects involving sleep elite athletes
    - future directions for research into 'sleep and athletic performance

ENGLISH INSTITUTE OF SPORT

EIS Sleep Roadshows 2016

Speakers:

- Sarah Gilchrist EIS Technical Lead Physiologist
- Luke Gupta, EIS PhD Student
- Professor Kevin Morgan, Professor of Psychology and Director of the Clinical Sleep Research Unit at Loughborough University
- Dr Maureen Tomeny, Consultant Clinical Psychologist and a visiting Fellow of the Clinical Sleep Research Unit (Loughborough University).

Purpose

- Upskill practitioners in all sports across the system in:
  - the fundamentals of sleep assessment
  - basic sleep literacy, and collecting and analysing useful and meaningful sleep data

Aims

- Preserve the 'sleep experts' time
- Access to the expertise we've built in house and externally is protected for the more challenging, important and impactful cases
- Workshop (& resources) are designed to help you be the 'go-to' person in your sport around basic sleep assessment and education
- Strengthen the high performance system around the topic of sleep

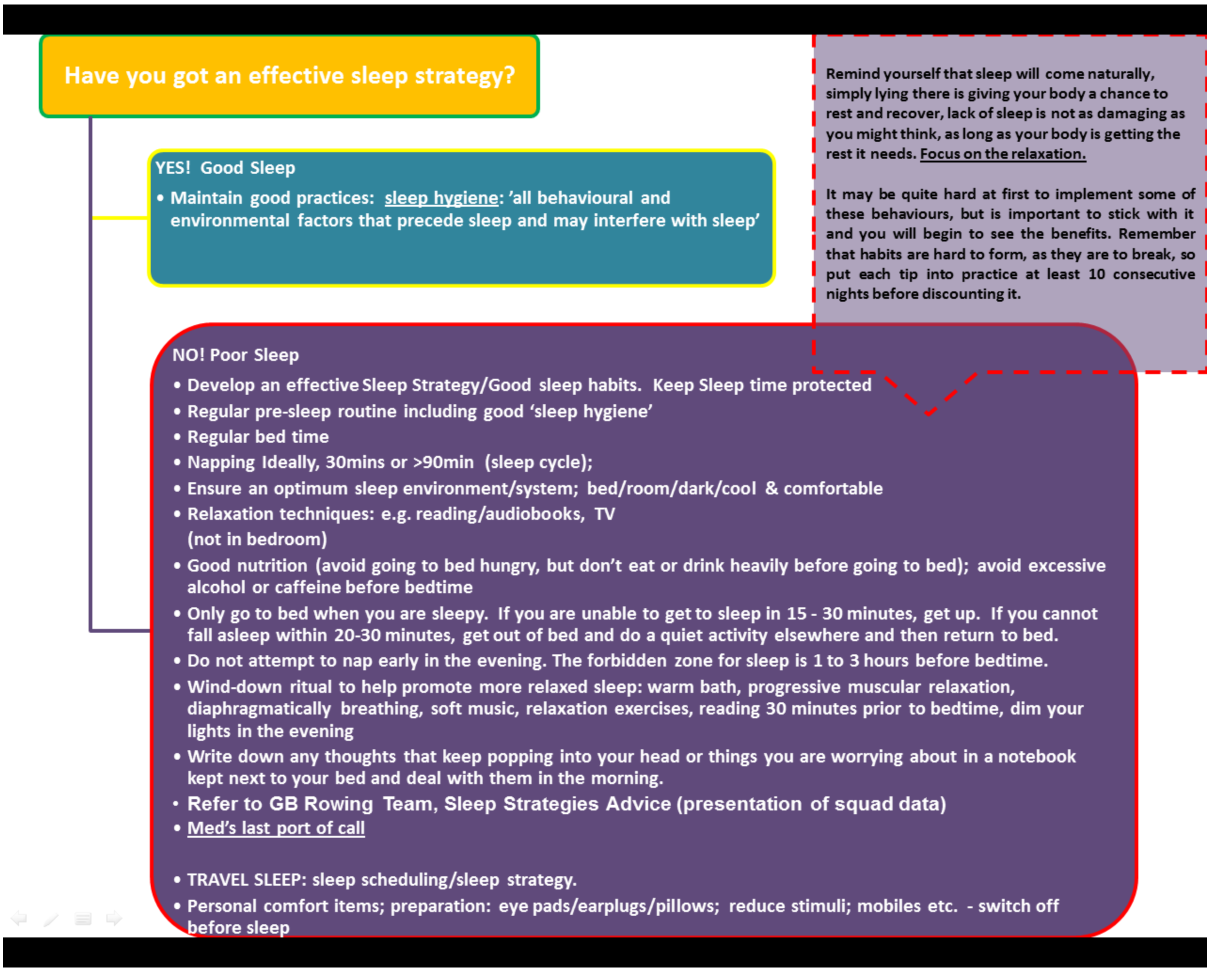
Appendix 4

- Sleep Strategy Flow Chart for Athletes

- Guidelines for Enhancing Sleep Behaviour (sleep hygiene)

- EIS Strategy for the Development of Assessment and Management of Athlete Sleep 2017-2021

Sleep Strategy Flow Chart for Athletes



Guidelines for Enhancing Sleep Behaviour

Sleep Behaviour

- All aspects in relation to your approach to sleep e.g. strategy, routine, hygiene, system
- Sleep hygiene: all behavioural and environmental factors that precede sleep.

Routine

- Regular bed and wake times will help sleep onset and ensure sleep is maintained throughout the night
- To obtain 7 - 8 hours sleep per night aim to spend 8 – 9 hours in bed. Set a wake-up time and work backwards in 90 min cycles to get the right bed-time (sleep inertia)

Sleep system

- HOME: Use your bed for sleeping only, otherwise your body will associate it with other things apart from sleep!
- AWAY: Normal for the first night spent in a new location to consist of disturbed sleep and cannot be prevented. Sleep is often disturbed due to unfamiliarity with the environment and can be minimised by making the room feel like home
- Hotel bedding can be uncomfortable (unlike home) and can cause disturbed sleep. Bring small items of bedding such as pillow to help your body think it is at home

Neutral bedroom temperature

- Core body temperature decreases during the evening. This decrease is associated with the onset of sleep, therefore a hot environment will not aide sleep.
- Plan ahead, if your room is hot then open a window or use a fan before you plan to sleep to cool your room. Equally if you are too cold in bed then use a blanket or hot water bottle to find a comfortable temperature to sleep in.
- During the night the body’s core temperature drops to it’s lowest and therefore a thermo-neutral environment is important ensure sleep is maintained
- Warming the skin will help the body’s temperature drop to what is needed for sleep. Having a warm-bath or wearing warm clothing can help this process

Nutrition

- Milk is high in a slow releasing protein and the warmth from the milk will enhance feelings of sleepiness
- A glass of warm milk before bed will help both sleep onset and muscle growth and repair during sleep following training
- Avoid drinking large volumes in the hour before bedtime, especially caffeine

Minimise light

- Exposure to bright light in the evenings delays the release of melatonin in the night. Depressed melatonin secretion has been shown to reduce sleep quality.
- Minimising light exposure 30 min before bed allows the hormone melatonin to peak causing feelings of sleepiness
- Exposure to bright light from electronics (TV/ tablet/ phone) is sufficient to suppress melatonin and delay sleep onset
- Curtains in hotels can be poor at blocking out light. Wearing eye masks can help early awakenings due to light entering the room in the morning

Avoid distractions

- Max 30' before bed ensure all social activities are satisfied
- Avoid noise and the use of stimuli e.g. electronic and social media as these can be associated with sleep disorders through causing increased arousal prior to sleep and emitting blue light which stimulates the brain and dresses the release of serotonin
- Ear plugs are a good solution to ensure noise is kept to a minimum
- Room mates on camp can disturb one another's sleep when they have different sleeping habits. Try and choose a room mate who has similar sleep patterns and has a similar chronotype (morning or evening person)
- It is tempting to watch TV in bed which can delay sleep onset. Where possible watch TV out of the bed and keep your bed for sleep only. Your body should associate your bed with sleep and not being awake.

EIS Physiology: Strategy for the Development of Assessment and Management of Athlete Sleep

VERSION	1.0
INITIAL DATE	June 2016
LAST REVIEW DATE	
AUTHORS	Sarah Gilchrist
RESPONSIBILITY FOR UPDATES	Sarah Gilchrist

EIS Physiology: Strategy for the development of assessment and management of athlete sleep

Background

For high performance athletes athletes, sleep and recovery between training bouts are paramount for optimising delivery of performance in training and competition. However, sleep quality and sleep structure among high performance athletes are challenged by the physiological and emotional stress of training and competition, and the circadian demands of integrating training programmes into athlete lifestyles. Concerns over poor sleep quotas in the athletic population stem from the knowledge that despite individual requirements for sleep displaying large variations, chronic reduction in sleep can lead to immuno-suppression (Reilly & Edwards, 2007) and thus athlete wellbeing suffers.

Sleep and athletic performance have developed interest in popular and academic literature over recent years. Anecdotal and limited empirical evidence indicates high performance athletes, as a group, experience degraded sleep quality relative to non-athlete controls (Leeder *et al.*, 2012), and this sleep disruption is amplified during and immediately after competitions (Erlacher *et al.*, 2011).

Conversely, emerging evidence suggests improved sleep quality can enhance individual (Skein *et al.*, 2011) and team (Mah *et al.*, 2011; Zhao *et al.*, 2012) athletic performance. However, the robustness of, and possible mechanisms mediating these effects remain unknown. In addition, the nature and effectiveness of sleep management strategies to maintain performance following circadian challenge remain either undeveloped, or untested.

It is supposed that sleep and athletic performance have a reciprocal relationship and this has not yet been fully investigated in the high performance sport arena. Sleep and associated movement behaviour are often described as a ‘recovery’ process yet the mechanisms, characteristics and quality of which have not been conclusively reported.

Sports science practitioners have traditionally employed a battery of assessments to characterise and measures athlete adaptation and recovery from training. To date sleep and associated movement behaviour have not traditionally been part of this assessment battery yet sleep is a physiological process which the physiologist should feel compelled to profile in an elite athlete.

Since 2013 the EIS in collaboration with Loughborough University have supported a PhD investigating the global concept of sleep and athletic performance. Critical to this is the link we have established with Professor Kevin Morgan, director of the Clinical Sleep Research Unit (CSRU) at Loughborough University and Professor of Psychology. He specialises in the origins, assessment and treatment of insomnia-type sleep disorders, and inter-relationships between sleep quality and high performance sport.

Benefits to the EIS

Several opportunities throughout the Rio cycle have ensured there is now a breadth of basic knowledge across the organisation relating to normative values and techniques for the management and education of sleep for athletic performance. Examples such as the sleep PhD, bespoke projects to sports and internal and external knowledge outlets have enhanced the EIS impact on sleep and performance as we have benefited from a network of multidisciplinary practitioners who have consistency of message, collaborative and quality assured practices, all coupled with development of technology utilised.

Purpose

As we transition into the next Olympic/Paralympic cycle there is a need to consolidate the information we have and plan ahead for how we can impact on sports with further investigations and knowledge gain in the area of sleep and athletic performance.

The Tokyo cycle will bring specific performance questions relating to sleep duration and quality, sleep extension, sleep scheduling and circadian rhythm challenges. As an organisation focused on excellence in sports science and sports medicine we need to act on existing research conducted and lead the applied research pertaining to such questions into the next Olympic cycle.

Therefore the overall aim of this document is to provide information on work conducted to date and several objectives for improving and developing the EIS work flow in relation to sleep and athletic performance. Furthermore, several solutions are proposed for how these objectives could be achieved.

Projects, outputs and intelligence to date

Considerable work has been completed across the physiology discipline in collating normative data on athletic sleep quality and structure. Bespoke projects have been conducted with sports to provide intelligence on athletes' sleep in preparation for international competition. Practitioners have also presented internationally and locally within the EIS, for example, to introduce the concept of assessment and management of athletes sleep and to inform practitioners how to measure sleep. Most recently, national roadshows have been conducted targeting key areas in the EIS network where maximum impact in disseminating information regarding sleep could be achieved. The objectives of these roadshows were threefold; firstly to upskill practitioners in all sports across the system in the fundamentals of sleep assessment, basic sleep literacy, and collecting and analysing useful and meaningful sleep data. Secondly, to serve to strengthen the high performance system around the topic of sleep, and thirdly to preserve the time that the 'sleep experts', were spending dealing with athletes for the most challenging, important and impactful cases.

Further, whilst the PhD is currently in progress it has already produced results displaying the intrinsic relationship between physiology and sleep and how we can impact on margins of performance through improved sleep strategies, knowledge and assessment.

The outcomes of such workflows have led to the below objectives being identified for future impact in the assessment and management of athlete sleep.

Objectives

Table 1. Strategy objectives and key performance indicators for the assessment and management of athlete sleep

Objective	Key Performance Indicators
Disseminate findings from EIS PhD: 'sleep and athletic performance'	• Practitioners are educated on current findings on sleep and athletic performance • Athletes, coaches and practitioners have a heightened awareness of sleep and why it needs to be managed for their wellbeing and performance

	Athletes report a greater understanding of sleep and wellbeing/performance than post London 2012 (repeat 'sleep questionnaire' of 2014)
Formal collaboration with Loughborough University for access to online resources for athletes, coaches and practitioners	- Current online resources produced by Loughborough University for managing insomnia and sleep problems are modified to be tailored to the high performance sport industry and made available by secure portal access - Specific EIS practitioner responsibility for the dissemination, up keep and development of the online resources in collaboration with Loughborough University's clinical sleep research unit.
Establish an EIS focus group on 'sleep and athletic performance'	- Physiology extends collaboration with other disciplines through a defined working group focused on the acquisition, development and dissemination of technical knowledge around sleep and athletic performance - Through EIS heads of service, identify practitioners from key disciplines (related to sleep), who are united to form such a working group - Specific objectives identified to further impact on the sleep and athletic performance knowledge base for the Tokyo cycle
Integrate sleep profiling with other metrics that can help improve athletic performance	- Links established between information gleaned from objective and subjective sleep analyses and athlete wellbeing - Liaise with EIS 'athlete health' department in areas where sleep can add value to PDMS
Targeted sleep research questions e.g. where sleep can now add value, investigate and provide some holistic solutions?	- Sleep can add value within all disciplines within the EIS. Below are a few topic areas as examples: - Sleep for health across the lifespan (Performance Lifestyle): The impact of high performance sport on insomnia development during retirement - Nutrition and sleep (Nutrition): the management of nutrition to optimise sleep (and chronobiology) - Sleep and training (Physiology/ S and C): Optimising training adherence and quality through sleep intervention e.g. sleep extension (napping) - Sleep management during competition (Psychology): The development of sleep strategies to manage sleep during competition - Sleep and long haul travel (Physiology/Nutrition): establish performance solutions for long haul flights, specifically for eastward travel - Sleep and skill acquisition (Performance analysis): understand the impact of sleep on sports in the higher skill acquisition domain - Sleep scheduling (Physiology/Nutrition/Psychology): understand chronobiology of high performance athletes e.g. larks vs. owls and its link to performance
Identify a pathway for referral for 'problem sleep' within sports (in collaboration with EIS Medicine and Psychology)	- EIS referral pathway for sleep is updated and modified for new Olympic cycle - Performance question or problem is formulated and referring practitioner uses EIS referral pathway for sleep solutions - Referring practitioners are upskilled to recognise whether performance problem requires sleep to be 'fixed' or proactively 'managed' i.e. does the athlete(s) have a specific problem with their sleep or are they about to undergo a phase of training during which

	sleep will be challenged (heavy training, altitude, travel, competition etc.)
Identify other technical areas where we can learn about sleep and new technologies relating to sleep e.g. mattresses/temperature control	• Develop further links within clinical domains in relation to sleep e.g. Papworth Respiratory Support and Sleep Centre • Understand other sleep theologies being developed through other parties and be prepared to offer scientific critique of them

Responsibilities

It is anticipated the above objectives and key performance indicators can be achieved through both existing positions within the EIS and our partnership with Loughborough University.

Nevertheless, there is a predictable challenge when the PhD is complete (2017/18), for delivery to sports of bespoke knowledge in sleep and athletic performance. Therefore it is anticipated as an organisation we should not only work towards retaining within the EIS the intellectual property, skills and attributes gained during the PhD, but also further develop the topic for the reasons outlined in this document. Suggested solutions for this would be:

1. A core funded position in partnership with sports(s) who need direct physiology input but not on a full time basis
2. A core funded part time post in partnership with a post-doctoral position with Loughborough University
3. An additional practitioner within the institute's physiology team with specific expertise in sleep and athletic performance
4. The attainment of protected time for sleep work flows for existing practitioners

Summary

In summary there is scope for the area of sleep and athletic performance to continue to have impact across all sports, both Olympic and non-Olympic, at least for the next four years. In striving to improve performance through Sports Science and Medicine we should address this area as a 'super strength idea' and look to invest where we can in the creating a legacy of performance impacting sleep research in sports science .

References

Reilly T and Edwards B. 2007. Altered sleep-wake cycles and physical performance in athletes. *Physiol Behav.* 28;90(2-3):274-84

Leeder, J., Glaister, M., Pizzoferro, K., Dawson, J. & Pedlar, C. 2012. Sleep duration and quality in elite athletes measured using wristwatch actigraphy. *Journal of Sports science s* 30(6): 541–545

Erlacher D., Ehrlenspiel, F., Adegbesan, O. A., & Galal El-Din, H. 2001. Sleep habits in German athletes before important competitions or games. *Journal of Sports science s* 29(8): 859-866

Skein *et al.*s (2011) Intermittent-sport performance and muscle glycogen after 30 h of sleep deprivation. *Medicine and Science in Sport and Exercise*. 43(7): 1301 – 1311

Mah CD; Mah KE; Kezirian EJ; Dement WC. 2011. The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep* 34(7):943-950

Zhao *et al.* 2012. Red light and the sleep quality and endurance performance of Chinese female basketball players. *Journal of Athletic Training* 47(6): 673 – 678